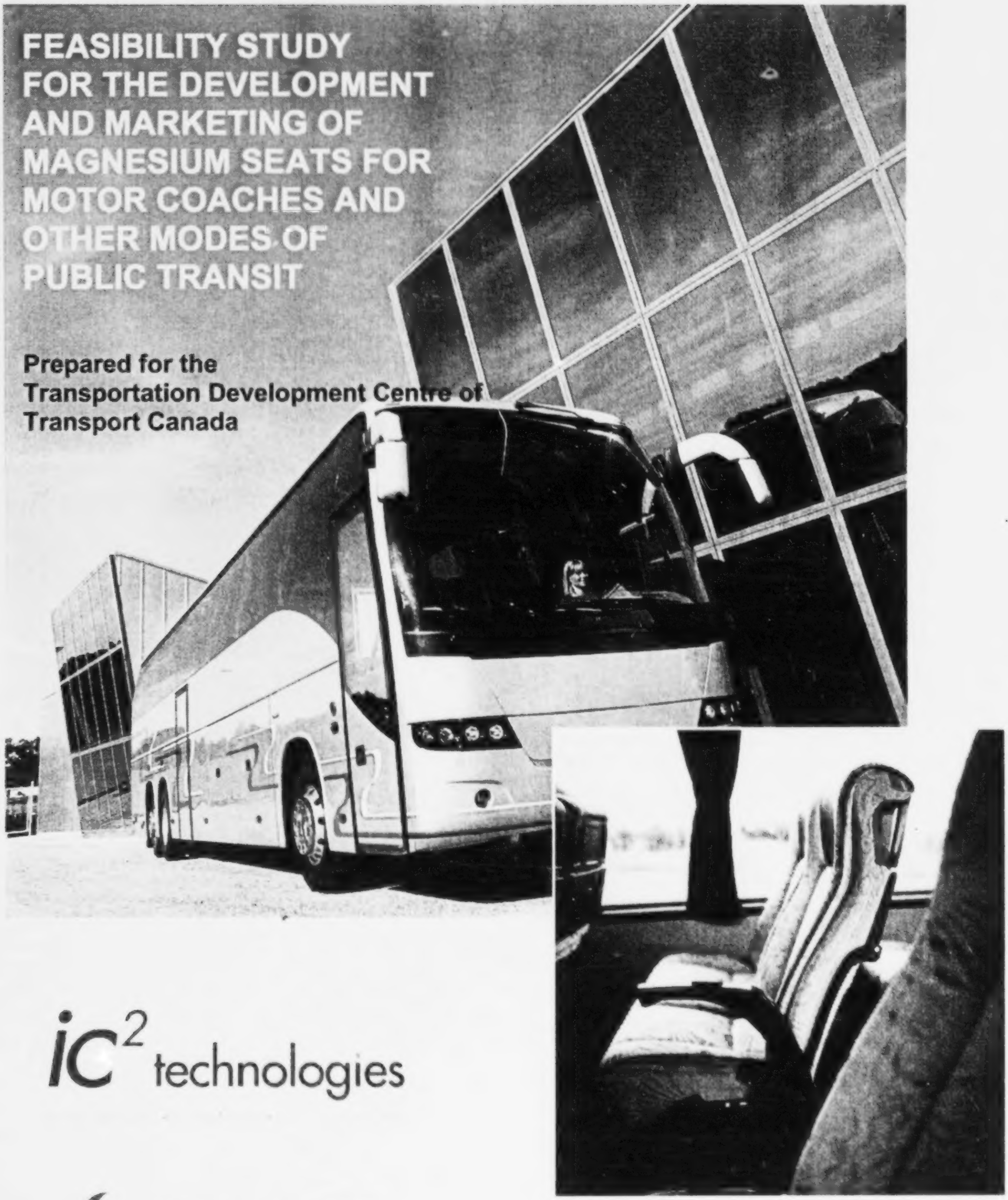
TP 14275E

FEASIBILITY STUDY FOR THE DEVELOPMENT AND MARKETING OF MAGNESIUM SEATS FOR MOTOR COACHES AND OTHER MODES OF PUBLIC TRANSIT

Prepared for the
Transportation Development Centre of
Transport Canada



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Stratégie d'affaires & ingénierie financière

June 2004

105-01700/

TP14275E

Feasibility Study for the Development and Marketing of Magnesium Seats for Motor Coaches and Other Modes of Public Transit

by

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June 2004

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Since some of the accepted measures in the industry are imperial, metric measures are not always used in this report.

Unless otherwise indicated, all monetary values in the report are in Canadian dollars.

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Ce rapport est également disponible en français : «Étude de faisabilité pour le développement et la commercialisation de sièges en magnésium pour les autocars et autres modes de transport en commun», TP 14275F.

Transport Canada Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No.
TP 14275E

2. Project No.
5488-89

3. Recipient's Catalogue No.

4. Title and Subtitle
Feasibility Study for the Development and Marketing of Magnesium Seats for Motor Coaches and Other Modes of Public Transit

5. Publication Date
June 2004

6. Performing Organization Document No.

7. Author(s)
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8. Transport Canada File No.
2450-JP06

9. Performing Organization Name and Address

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10. PWGSC File No.
MTB-3-01286

11. PWGSC or Transport Canada Contract No.
T8200-033529/001/MTB

12. Sponsoring Agency Name and Address

Transportation Development Centre (TDC)
800 René Lévesque Blvd. West
Suite 600
Montreal, Quebec
H3B 1X9

13. Type of Publication and Period Covered
Final

14. Project Officer
Claude Guérette

15. Supplementary Notes (Funding programs, titles of related publications, etc.)
Co-sponsored by the Program of Energy Research and Development of Natural Resources Canada

16. Abstract

This study was carried out to address concerns about the use of magnesium to manufacture lighter seats for public transit vehicles, particularly motor coaches. The study helped validate the feasibility of magnesium and/or aluminum passenger seats and whether they would meet the weight and cost reduction objectives sought by the public transportation industry.

In the course of the study, the North American bus and motor coach market was assessed, passenger seat design standards in North America, Europe and Australia were reviewed, and magnesium samples were tested to ensure that this material meets public transit industry standards for material flammability and for toxic fumes possibly emitted during exposure to intense heat.

The costs of manufacturing passenger seats using various moulding technologies were assessed in order to compare the competitiveness of a magnesium and/or aluminum solution in relation to the conventional steel solution. It was concluded from the case study carried out that a lighter-seat solution was both technically possible and economically viable.

17. Key Words
Magnesium, aluminium, seat, passenger, motor coach, bus, weight reduction, flammability, cost, feasibility

18. Distribution Statement
Limited number of copies available from the Transportation Development Centre

19. Security Classification (of this publication)	20. Security Classification (of this page)	21. Declassification (date)	22. No. of Pages	23. Price
Unclassified	Unclassified	—	xxv, 77, apps	Shipping/ Handling

CDT/TDC 79-005
Rev. 96

Canada

Transports Canada Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. Nº de la publication de Transports Canada
TP 14275E

2. Nº de l'étude
5488-89

3. Nº de catalogue du destinataire

4. Titre et sous-titre
Feasibility Study for the Development and Marketing of Magnesium Seats for Motor Coaches and Other Modes of Public Transit

5. Date de la publication
Juin 2004

6. Nº de document de l'organisme exécutant

7. Auteur(s)
François Bergeron et Jean-François Audet

8. Nº de dossier - Transports Canada
2450-JP06

9. Nom et adresse de l'organisme exécutant

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10. Nº de dossier - TPSGC
MTB-3-01286

11. Nº de contrat - TPSGC ou Transports Canada
T8200-033529/001/MTB

12. Nom et adresse de l'organisme parrain

Centre de développement des transports (CDT)
800, boul. René-Lévesque Ouest
Bureau 600
Montréal (Québec)
H3B 1X9

13. Genre de publication et période visée
Finale

14. Agent de projet
Claude Guérette

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)
Projet coparrainé par le Programme de recherche et développement énergétiques (PRDE) de Ressources naturelles Canada

16. Résumé

La présente étude a été réalisée afin de lever certaines incertitudes face à l'utilisation du magnésium pour la fabrication de sièges plus légers pour le secteur du transport en commun et plus particulièrement pour le secteur des autocars. Cette étude a permis de valider la faisabilité d'un siège pour passager en magnésium et/ou aluminium rencontrant les objectifs de réduction de poids et de coût recherchés par l'industrie.

Le marché nord-américain des autobus et des autocars a été évalué, les différentes normes de conception de sièges pour passagers en Amérique du Nord, en Europe et en Australie révisées et des échantillons de magnésium ont été testés afin de s'assurer que ce matériau répondait aux normes de l'industrie de transport de masse quant à l'inflammabilité des matériaux et l'émission de fumée toxique pouvant être émise lors d'une exposition à des chaleurs intenses.

Une évaluation des coûts de fabrication d'un siège pour passager à l'aide de différentes technologies de moulage a été réalisée afin de comparer la compétitivité d'une solution utilisant le magnésium et/ou l'aluminium en référence avec la solution conventionnelle en acier. L'étude de cas réalisée permet de conclure qu'une solution de sièges plus légers est à la fois possible techniquement et viable économiquement.

17. Mots clés
Magnésium, aluminium, siège, passager, autocar, autobus, allégement, inflammabilité, coût, faisabilité

18. Diffusion
Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

19. Classification de sécurité (de cette publication)
Non classifiée

20. Classification de sécurité (de cette page)
Non classifiée

21. Déclassification (date)
—

22. Nombre de pages
xxv, 77, ann.

23. Prix
Port et manutention

ACKNOWLEDGEMENTS

This study was made possible through the close co-operation of Transport Canada and industry representatives. In particular, the authors would like to thank Claude Guérette (Transport Canada), Eric Belval and François Giguère (Multina), Alain Dulac and Raymond Blackburn (Prévost Car), Len Miller and John Izydorczy (Meridian Technologies) and Pierre Labelle (Noranda) for their contributions.

The authors would also like to thank all those who answered our questions and participated in our interviews. The full list of interviewees is included in Appendix A.

Lastly, the authors wish to thank the participating firms – Magnesium Elektron, Magparts, Meridian Technologies, Powercast, Thixomat, Thixotech, Thompson and Genistar – for allocating resources to prepare submissions used to prepare the case study in Chapter 4 and/or providing magnesium samples for the flammability tests outlined in Chapter 3.

The cover page photographs were provided courtesy of Volvo Bus Corporation. The photographs of magnesium parts on pages 45 to 48 were provided courtesy of Meridian Technologies and Honsel Fonderie Messier.

SUMMARY

STUDY BACKGROUND

This study was conducted for Transport Canada's Transportation Development Centre in order to dispel doubts about the use of magnesium to manufacture lighter-weight seats for the public transit industry, particularly the motor coach industry. The study's objective was to validate the feasibility of magnesium seats and propose a plan of action for developing and validating initial prototypes.

Although aluminum solutions were also options taken into consideration in this study, the magnesium solution offered the best scenario in terms of weight reduction and therefore priority was given to determining its viability. It will become clear upon reading this analysis that a range of options is possible: an all-aluminum solution, an all-magnesium solution or a combination of these materials. The final choice will depend on manufacturers' specific objectives and desired compromises in terms of weight reduction, cost reductions, comfort and safety.

Because magnesium seats are more luxurious and expensive than those in urban transit buses and North American manufacturers are receptive to their use (unlike the typically more conservative intercity rail industry), the motor coach industry was selected as the first market that could benefit from the introduction of magnesium seats. The issue analysis and the case study therefore focus on this initial target market. However, the study highlights similarities between the motor coach market and the train market, which could be a second market. Once economies of scale are realized, the urban bus market could, in turn, certainly benefit from the expertise developed in the motor coach industry.

Lower vehicle weight is recognized for its many benefits and is becoming a major issue in terms of environmental considerations, road safety and emerging new energy sources. The benefits include lower fuel consumption, lower polluting emissions levels, increased safety, greater viability of new energy sources and less damage to roads.

In 2000, Transport Canada launched a study to define the problem of motor coach weight and conducted a technical study of motor coach frames and components in order to identify lighter-weight options. As this study points out, there is a recurring problem of motor coaches exceeding the weight limits for various types of axles:

> *In 1988, a memorandum of understanding (MOU) was developed under the auspices of the Transportation Association of Canada to bring about greater uniformity in provincial regulations regarding vehicle size and weight. Under the MOU, the weight limits of the front, drive, and tag axles were set at 5,550 kg, 9,100 kg, and 6,000 kg, respectively. Surveys revealed that out of a total of 140 observations, 50 percent of the buses had steering axle weights exceeding 5,500 kg. In 1997 the front axle capacity was increased to 7,250 kg. Recent surveys indicate that out of 200 observations, 3 percent of buses had the steering axle over the new regulated limit and 18 percent had a weight on their drive axle exceeding*

> *the 9,100 kg limit. Therefore, the weight problem had been regularly identified as exceeding regulatory limits.*[1]

In early 2004, a second phase of this study was proposed. Its objective was to reduce the empty weight of a 45-ft. motor coach by 20% using an optimized design and high-tech materials for the roof and floor structures and other components. Although seats usually account for only 4% of the weight of a city bus or motor coach, lightweight alternatives can generate substantial savings relatively easily and without major vehicle modifications. This report, part of continuing efforts in that regard explains how these savings may be achieved.

NORTH AMERICAN PUBLIC TRANSIT MARKET

Motor coaches

There are some 40,000 motor coaches operating in the United States and 4,000 in Canada. The United States also has some 3,600 fleet operators, while Canada has 400. Of these, nearly 90% have fewer than 25 vehicles in their fleets and 75% have fewer than 10 vehicles. The 50 biggest operators (in terms of vehicles in service) account for about 30% of the North American motor coach market.

In Mexico, there are 30,000 to 40,000 motor coaches in operation to provide intercity services. In fact, motor coaches account for over 97% of intercity public transportation in Mexico because the passenger rail network is virtually non-existent and air transportation is very costly. According to Volvo Bus of Mexico, about 50% of Mexican motor coaches are economy class, 42% are first class and 8% are executive class.

Total motor coach sales in the United States and Canada were 2,400 units in 2002 and 1,770 units in 2003. After posting strong growth in the 1990s, the market has been steadily shrinking since 1999 (a cumulative decrease of about 50%). According to the most conservative opinions, sale volumes are returning to the average level of recent decades, or about 1,500 units per year. According to more optimistic opinions, estimated annual sales should return to between 2,800 and 3,200 units during the 2004–2007 period.

In Mexico's case, total motor coach sales were approximately 1,900 units in 2003, which was the average number for the previous five years. The Mexican market posted substantial growth of between 1,200 and 2,800 units between 1999 and 2001 and then dropped to between 1,800 and 1,900 units in 2002 and 2003. It is important to remember that the Mexican market is as big as the Canadian/American market.

Assessment of the passenger seat market

Table 1 provides an overview of the passenger seat market for various modes of ground public transit in North America.

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[1] Martec Limited, *Intercity Bus Weight Reduction Program – Phase 1*, Transportation Development Centre, Montreal, January 2000, TP 13560E.

Table 1. Estimated North American Market for New Seats in the Ground Public Transit Industry (New Vehicles)

	Urban Buses	Motor Coaches	Urban Trains	Intercity Trains
	Typical Number of Seats per Vehicle			
	40	50	56	60
	Projected Annual Market for New Vehicles			
Canada	400	150	80	N/A
United States	4,600	1,350	630	N/A
Mexico	2,500	1,900	N/A	---
	Estimated Number of New Seats			
Canada	15,000	7,500	5,000	N/A
United States	185,000	67,500	35,000	N/A
Mexico	100,000	95,000	N/A	---
Total	**300,000**	**170,000**	**40,000**	N/A
	Typical Price per Double Seat (Original Seat)			
	$400-$500	$700-$2,000	Heavy-rail and light-rail train cars: $450-$900 Commuter train cars: $900-$2,000	$1,000-$3,000

NB: In this table, a seat corresponds to a seat for one passenger.

The above estimates only take into account the market for new vehicles. It should be noted that there is also a market for seats used for vehicle repairs (particularly in the railway industry).

CURRENT APPLICATIONS FOR MAGNESIUM SEATS

Nowadays, the automobile industry regularly uses magnesium to manufacture seat frames just as it does to make instrument panel frames, steering wheel frames and various support components. The process normally used is high-pressure die casting. Magnesium is used for the seats in many minivans and luxury cars, in some high-speed trains, and for the seats used by drivers of heavy trucks.

SEAT DESIGN STANDARDS

There are no specific standards in North America for the design of motor coach passenger seats. Except for school buses, for which there are specific passenger seat standards, other current Canadian and American standards mainly apply to drivers' seats or seats fitted with seatbelts.

Many United States seat manufacturers use the American Public Transit Association (APTA) standards (Standard Bus Procurement Guidelines) as a reference. Although these standards are mainly intended for designers of urban bus seats, they can also be used as a reference for manufacturing motor coach seats. APTA standards for commuter train passenger seats are not as strict as the Australian standards described below.

Table 2. Comparison of International Standards for Motor Coach Passenger Seats

Load Type		Load Description	Standard		
			APTA (USA)	ECE 80 (Europe)	ADR 68 (Australia)
	Seat	Horizontal force (applied simultaneously) – H1 position on seatback – H2 position on seatback – distributed evenly on seatback	2.23 kN	1.0 kN @ 70-80 cm 2.0 kN @ 45-55 cm	1.0 kN @ 70-80 cm 2.0 kN @ 45-55 cm
		Vertical force - cushion	2.23 kN	(See force on anchorage)	
		Moment load applied to the upper part of the seatback	N/A	N/A	530 Nm
	Anchorage	Force applied to anchorage (double seat)	2.25 kN x 2 = 4.5 kN	10 kN	[8.9 kN (cushion) + 17.7 kN (seatback)] x 2 = 53.2 kN
Dynamics	Seat and anchorage	Average deceleration (G = 9.81 m/s^2)	10 G	6.5-8.5 G	20 G
		Minimum speed of car during impact simulation	N/A	30-32 km/h	49 km/h
		Speed of pendulum simulating shock to the head	N/A	N/A	6.69 m/s
		Acceptability Criterion			
		- Head	< 400	< 500	< 1,000
		- Thorax	N/A	< 30 G	< 590 m/s^2 (60 G)
		- Femur	4.45 kN	< 10 kN and the value of 8 kN must not be exceeded for more than 3 ms	< 10 kN

The Economic Commission for Europe (ECE) is the organization responsible for enacting legislation relative to seats for large-size passenger transit vehicles in Europe and for approving such seats. Although ECE standards are still not mandatory, European motor coach and seat manufacturers take them into consideration. As for North America, it was learned in discussions with seat manufacturers and motor coach manufacturers who manufacture their own seats that these European standards are often used as a reference.

The Australian standards (Australian Design Rules or ADR) are the strictest in the industry. In contrast to the European and North American standards, the wearing of three-point seatbelts has been mandatory since the early 1990s.

Table 2 provides a summary of these three sets of standards.

TESTS AND VALIDATIONS

Tests used to approve materials

In addition to the Canada Motor Vehicle Safety Standard and Federal Motor Vehicle Safety Standard No 302 (CMVSS/FMVSS 302) required by the automobile and motor coach industries, APTA requires three additional American Society for Testing and Materials (ASTM) tests [ASTM E 162, ASTM E 662 and ASTM E 1354] and Bombardier Transportation requires a fourth test (SMP-800-C) in order to certify any new material.

The results of the tests carried out by the independent firm Bodycote in Ontario demonstrate that AM60 and AZ31 magnesium alloys meet these standards for evaluating flammability of materials and toxic smoke emissions likely to be released during exposure to intense heat.

Corrosion test

Seats, being internal components of a vehicle, are not exposed to the weather. However, the part of the seat coming into direct contact with the floor (anchoring structure) can be exposed to snow, water, salt and cleaning products. In the seat design used for the case study, an extruded aluminum part is used to anchor the seat to the floor to ensure better mechanical properties and replicate an anchoring configuration used in several European seat designs.

Frames for cushions and seatbacks can be designed to eliminate the retention of liquids (soft drinks, coffee, water, etc) accidentally spilled on the seats, thus preventing galvanic corrosion in the presence of other materials. Since magnesium can corrode very quickly if placed in a galvanic environment, it must always be insulated with neutral materials (such as polymers) to prevent it from turning into a sacrificial electrode when in direct contact with aluminum, cast iron or steel in an aqueous environment.

It should be mentioned that magnesium seat frames used in automobiles are not given surface anti-corrosion treatment because these parts are not in direct contact with corrosive elements.

Comparison with automobile industry tests

Automobile seats are subject to the CMVSS/FMVSS 207 standard. When this standard is compared with the ECE 80 standard or even the ADR 68 standard, one can see that the specifications for a new magnesium passenger seat for motor coaches are not as strict as those for automobile seats.

Upon making this comparison, it becomes clear that *a lighter-weight passenger seat can be designed for motor coaches because (1) we know that magnesium seats are already used in the automobile industry and (2) when these magnesium seats were approved, they were tested with loads equivalent to and/or higher than the strictest motor coach industry standard.*

In the various tests carried out on magnesium instrument panels by the automobile industry—particularly energy absorption tests where an occupant not wearing a seatbelt is thrust directly against the part concerned—it was demonstrated that *there should not* *be any major problems involved in designing a new magnesium passenger seat for motor coaches that is capable of supporting and absorbing the energy of a rear occupant thrown forward against the back of the seat in front.*

IDENTIFICATION OF MANUFACTURING TECHNOLOGIES

Table 3 lists various technologies selected for the case study. In the case of permanent mold casting, a bid for aluminum parts was also requested so that a hybrid solution combining magnesium and aluminum could be considered for cost reasons if necessary.

Table 3. Lightweight Seat Design Technologies Assessed

Process	Mg	Al	Number of Suppliers Contacted	Suggested Alloys
Gravity casting processes				
Sand casting	X		2	AZ91
Permanent mould casting	X	X	3	AZ91, A413 and A356
Pressure die casting processes				
Horizontal press	X		1	AM60B and AJ62L
Vertical press	X		1	
Thixomolding^{TM}	X		2	
Number of suppliers			7	

NB: All contacted suppliers were in North America.

SEAT DESIGN USED FOR THE CASE STUDY

The design used for the case study was developed as part of the feasibility study conducted for Meridian Technologies in which the costs of developing a steel seat and a new magnesium seat were compared. This seat design is shown in Figure 1, while Figure 2 shows the typical steel design used by Prévost Car.

The magnesium design consists of the following: a single moulded part comprising the lower part of the seat; two seatbacks; armrests; and an extruded part for anchoring the seat to the motor coach floor. The monocoque cushion support is the key component of this design because it is the part to which the backrests, armrests, extruded parts and various seat position adjustment mechanisms are attached. The cushion support is fastened to the motor coach frame in two different places. Its aisle side end is attached to the extruded anchoring post directly bolted to the floor, and its opposite end is fastened directly to the inside wall of the motor coach beneath the windows.

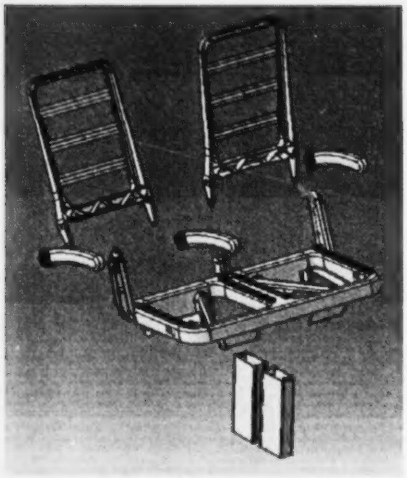

Figure 1. Monocoque Passenger Seat Design Used by Multina and Meridian Technologies (2002)

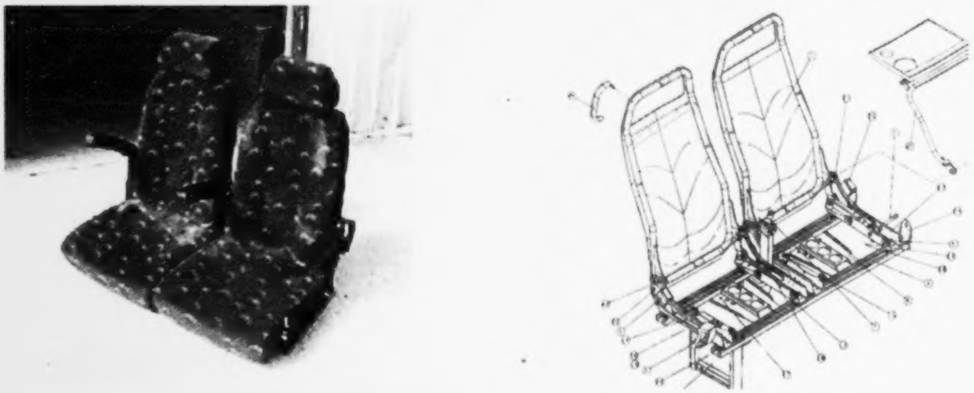

Figure 2. Steel Seat Currently Used by Prévost Car and as a Reference for the Case Study

The bottom support for the seat is made of extruded material because it undergoes considerable stress during a collision. Therefore, in order to minimize the risk of injury to passengers thrown forward during a major collision and the additional costs related to an anti-corrosion coating, the proposed design uses extruded aluminum parts, which have better mechanical properties than cast magnesium parts. After consulting various seat and motor coach manufacturers, we were able to validate the soundness of this decision from both a technical and economic standpoint.

According to the data from the feasibility study conducted for Meridian Technologies, this magnesium design (double seat) results in a weight reduction of more than 20 kg, or a decrease of up to 45%, compared with the complete (whole seat assembly) steel solution used by Prévost Car.

However, since the structural analyses have not yet been carried out on this seat design, and given that the final weight will vary depending on whether the manufacturer decides to design it with or without a three-point seatbelt, a weight reduction of 15 kg per double seat can be deemed reasonable. This amounts to a total reduction of about 375 kg per 50-passenger motor coach.

Description of cost reductions associated with magnesium seats

When comparing the costs of a monocoque magnesium solution with the costs of a steel solution, several substantial savings were found, particularly in terms of assembly costs and fewer rejected parts. For example, the estimated reduction in the cost of assembling a magnesium double seat was $2.00 (for the sales volumes listed in Table 4 for the first eight years of production), compared with the cost of assembling an equivalent steel seat.

CASE STUDY

Table 4. Projected Sales Volumes for the First Eight Years

Development and Marketing Phase		Estimated Annual Volume			
		Number of Buses Equipped with New Seats	**Number of Double Seats**	**Monocoque Cushion Supports**	**Seatbacks**
Prototypes	Yr 0	1	**25**	x 1 unit	x 2 units
Commercial launch	Yr 1	10	**250**		
Production	Yr 2	20	**500**		
	Yr 3	40	**1,000**		
	Yr 4	60	**1,500**		
	Yr 5	100	**2,500**		
	Yr 6	150	**3,750**		
	Yr 7	200	**5,000**		
	Yr 8	300	**7,500**		

Table 4 shows the projected annual numbers of double seats used for the cost estimate in the case study. These numbers take into account an initial prototype phase (for a bus) and eight years of mass production.

Analysis of costs of various casting technologies

Because the presses for vertical injection die casting and Thixomolding processes do not have sufficient capacity to produce monocoque cushion frames, each of these processes was assessed only for its capacity to produce seatback frames, then assessed in combination with conventional pressure die casting to determine the capacity to produce monocoque frames.

The analysis of equipment costs and production costs for each selected technology came up with the following findings:

- To make prototypes and for validation phase purposes, sand casting is the process requiring the least amount of investment;
- Up to a cumulative volume of 5,000 to 5,250 double seats, the permanent mould casting process offers the lowest costs and minimum of investment;
- Based on the total accumulated costs (equipment and production costs), the magnesium solution using permanent mould casting requires less capital than a conventional steel solution, up to a total volume of between 8,000 and 9,000 units (although the equipment costs for the steel solution are amortized over a much longer service life, its acquisition cost is higher than the cost of permanent mould casting);
- As soon as the total volume of production exceeds 5,250 units, the option combining the conventional pressure die casting process for monocoque seat base frames with the Thixomolding process for seatback frames offers the lowest cost. However, this option requires two suppliers rather than one;
- The option using vertical injection pressure die casting is less costly than conventional pressure die casting and is the second best option for large volumes. Keeping in mind that bigger-capacity presses will soon be available on the market, it would therefore be worthwhile to assess a complete solution using this technology.

For the first six years of production, we can conclude (based on the projected volumes in Table 4) that the permanent mould casting process is the best option given the uncertainty about volumes. Beginning in the seventh year, if demand continues to grow as forecast, a switchover to the solution combining pressure die casting and Thixomolding could be considered in order to take advantage of the competitiveness of these processes where bigger volumes are concerned. In fact, the projected volume starting in the sixth year (3,750 double seats, or some 150 motor coaches) is sufficient, if maintained in subsequent years, to justify a switchover to pressure die casting processes.

Figure 3 shows changes in the total accumulated costs, based on this scenario, of a switchover to other processes starting in the seventh year of production. We can see a significant increase in costs with the introduction of pressure die casting and Thixomolding processes because of high equipment costs, but the substantial accumulated savings in terms of the cost of parts ensures that the total accumulated cost falls quickly below that of the steel solution used for reference purposes starting in the following year, and also becomes clearly less expensive than permanent mould casting. In other words, the additional costs arising from the switchover to another process in the seventh year are completely absorbed a year after the switchover. This scenario therefore appears to offer a minimal investment risk while providing the best compromise in terms of cost.

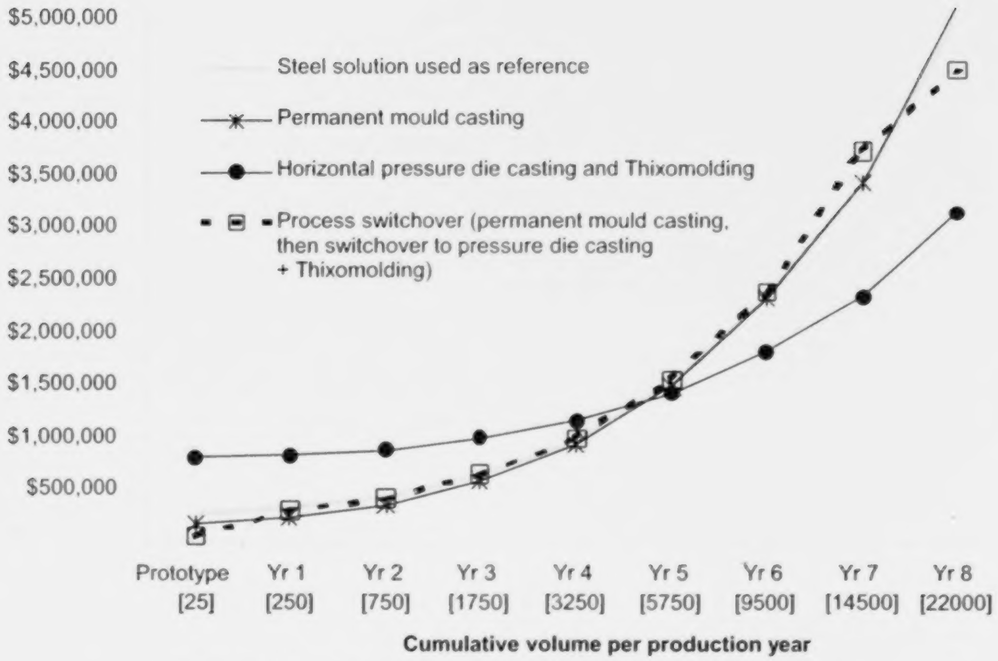

Figure 3. Cumulative Cost of Producing Double Seats (Equipment and Production Costs) Per Selected Scenario

Comparison of costs with those of the steel solution

Based on the above data, a net unit cost can be estimated for a magnesium double seat and compared with that of the equivalent steel solution currently used in the industry.

Based on projected volumes, Figure 4 shows changes in the net unit cost of using the permanent mould casting process as a long-term solution for manufacturing complete double seats as well as the net unit cost of the switchover scenario described above. Both processes are compared with the cost of the steel solution used as a reference.

Upon analysis, this figure shows that magnesium seats manufactured using the permanent mould casting method (as a long-term solution) represent an additional cost of 10 to 15% in the case of smaller quantities (up to 1,000 double seats or up to 40 motor coaches), compared with the steel solution, and a supplementary cost of 4% for bigger volumes (2,500 double seats or 100 motor coaches or more per year). Over the eight-year period, the average unit cost amounts to a additional cost of approximately 5%, compared with the cost of the steel solution used for reference purposes. In terms of cost savings per kilogram of less weight (metric measurements are often used in weight reduction analyses), this amounts to an additional cost of $2.33/kg for volumes of 250 seats per year, and a slight supplementary cost of $0.66/kg for bigger volumes.

For the scenario involving a switchover to another process along the way, the equipment costs for the permanent mould casting process are amortized for a smaller quantity, which affects costs. During the six years of production using this process, the total additional cost per unit would vary between 20% and 10%. If we take into account the average cost of parts for these six years of production using the permanent mould casting process, we obtain a supplementary cost of about 12%, compared with the steel solution. However, the savings become greater with the introduction of pressure die casting processes. In fact, the option combining pressure die casting and Thixomolding allows for a cost reduction of nearly 40%, compared with the steel solution.

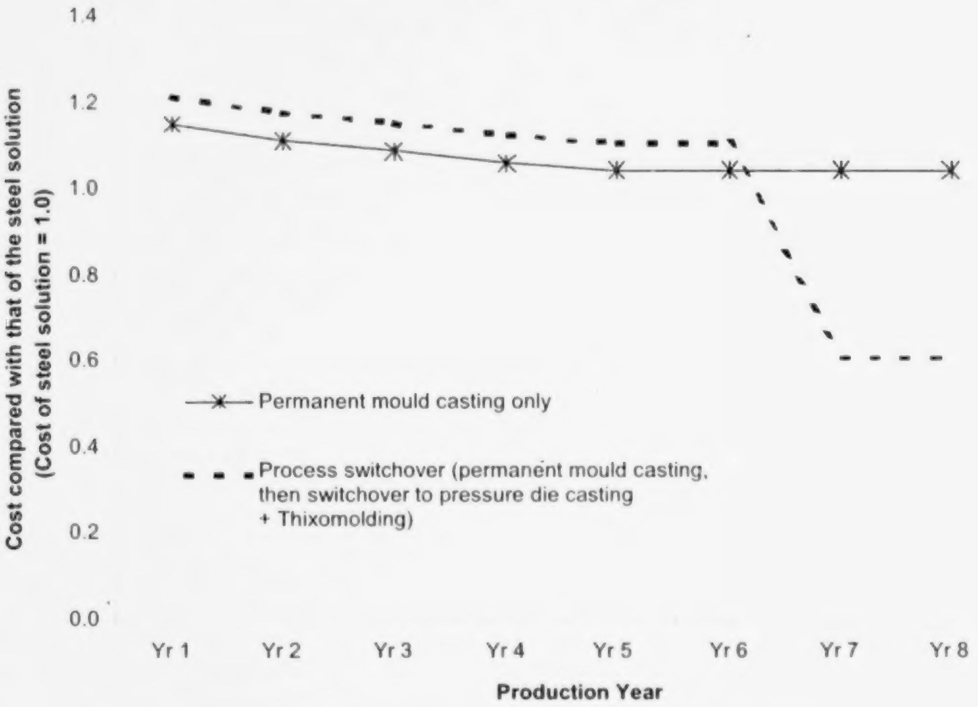

Figure 4. Net Unit Cost of a Complete Double Seat, Compared with That of the Steel Solution Used as a Reference

If we look at cost per kilogram of less weight in this scenario, there is an additional cost of $3.40 per kilogram of less weight using the permanent mould casting process for annual volumes of 250 double seats (10 motor coaches), compared with a saving of over $6.00/kg with pressure die casting processes. With volumes of over 2,500 units (100 motor coaches) per year, the additional cost can drop to $1.75 per kilogram of less weight, according to some motor coach manufacturers.

Impact on life cycle cost

Table 5 summarizes the economic impact of a weight reduction in motor coaches attributable to magnesium seats. For operators, a motor coach fitted with magnesium seats represents a direct saving of some $6,000 during the vehicle's service life. For major operators with fleets of several hundred motor coaches, this represents several million dollars of additional profit.

Table 5. Impact on Life Cycle Cost

Life Cycle Cost Component	Lower Costs Resulting from a Weight Reduction of 375 kg per Motor Coach	
	Annual saving per motor coach	Saving per motor coach life cycle (15 years)
Gasoline	$295	$4,425
Wear and tear on brakes and tires	$110	$1,650
Highway infrastructure	$264	$3,960
Polluting emissions	$176	$2,640
Total	**$845**	**$12,675**

In terms of reduced CO_2 emissions, a weight reduction of 375 kg per motor coach has relatively little impact: about 1.14 tonnes annually, or some 17 tonnes per motor coach during its estimated 15-year service life. Nonetheless, this weight reduction can be part of other technical solutions for lighter weight, thus helping to reduce CO_2 emissions.

Cost of a hybrid aluminum-magnesium solution

For the first phase of production, it is worthwhile to compare the cost of an all-magnesium solution using a permanent mold casting process with a hybrid solution combining aluminum and magnesium. The cost of the first hybrid solution can be obtained by calculating the cost of a magnesium monocoque base combined with two aluminum seatbacks, while the second hybrid solution can be obtained by combining the cost of an aluminum monocoque base with that of two magnesium seatbacks.

If we compare the costs with those of the steel solution used for reference purposes, the two hybrid solutions offer a cost saving as well as a weight saving. More specifically, the solution involving an aluminum monocoque base offers a saving of between 1% and 5%, compared with the steel solution, depending on volumes and the equipment amortization period. The solution involving aluminum seatbacks offers a saving of between 17% and 24%.

CONCLUSION

In light of the facts provided above, it appears that a lighter-weight seat solution is both technically possible and economically viable.

On the technical side, this study helped explain the following:

- In terms of flammability, magnesium meets all standards required by the automobile, motor coach and railway industries;
- Magnesium's ability to absorb energy during a collision, if combined with excellent seat design consistent with the casting process selected for production, could, in certain cases, increase the safety of seat occupants projected forward against the seatbacks in front of them;

- Magnesium's ability to absorb vibration should help reduce vibrations transmitted to passengers and provide greater comfort on long trips.

The final decision on the choice of materials (magnesium and/or aluminum) may vary, depending on the objectives of the seat manufacturer, motor coach manufacturer or final buyer. However, the following should be considered when selecting these materials:

- The development of a magnesium seat can result in a weight reduction of about 375 kg per motor coach, compared with less than 200 kg for an aluminum design;
- The greater the weight reduction, the easier it will be for operators to increase the payloads of their motor coaches or comply with the weight standards for various axles and reduce fuel consumption and wear and tear on parts, such as brakes and tires;
- The use of magnesium would make it possible to manufacture an ergonomic seat with thinner-walled parts than would be possible with aluminum;
- Magnesium's ability to absorb vibration is a substantial benefit, compared with aluminum.

If the targeted objectives are solely economic, the all-aluminum solution or a hybrid solution combining aluminum and magnesium are the best choices, despite the disadvantages when compared with an all-magnesium solution. However, the objective of this study was to determine the economic and technical viability of the lightest-weight solution, which was a magnesium seat. It was found that, at low volumes, a magnesium solution using a permanent mould casting process would result in an additional cost (ranging from slight to significant, depending on volume) and, to remain competitive at low volumes and to reduce costs, a hybrid solution must be considered. For larger volumes (2,700 double seats or more per year), a gradual move toward an all-magnesium solution using pressure die casting and Thixomolding processes would result on an optimal weight reduction and a significant cost reduction compared with the conventional steel solution.

To quickly obtain cost savings compared with the conventional steel solution, a commitment from a single manufacturer to switch over to a hybrid magnesium-aluminum solution may be sufficient. However, it is important to note that it would be in the interest of the industry as a whole to switch over to an all-magnesium solution (using pressure die casting and Thixomolding processes) and thus benefit all down the line (cost, weight and comfort).

RECOMMENDATIONS

Commercial aspects

Having taken the main facts set out in this study into consideration, the authors recommend the following with regard to the marketing potential:

- The development of a lighter-weight seat, either made of aluminum or in a hybrid form combining magnesium and aluminum, is now economically viable and should be the starting point for marketing a new line of products to replace steel seats.

- To quickly reach the volumes required to maximize the benefits of an all-magnesium solution, marketing activities should target not only the Canadian/American market, but also the Mexican market, within the context of the NAFTA. This market could be developed through strategic alliances.

  Moreover, since we know that the Mexican market and players in that market are also very close to the Brazilian market, and given that several manufacturers in these two countries are European, the marketing of such seats can quickly become international. Groups such as Volvo Bus (Prévost Car in Canada and Volvo Bus in Mexico), DaimlerChrysler (Setra in the United States and Europe, Mercedes in Mexico) and Irizar (Mexico, South America and Europe) can be targeted to promote adoption of the seats and rapid growth.
- Given the international potential of magnesium seats and the mechanical properties of magnesium alloys, it would be worthwhile to consider adapting the seat to meet European standards by including three-point seatbelts.
- Given the interest of certain high-speed train manufacturers, it would be possible to consider a seat design that could also meet the needs of this industry, which would increase production volumes and significantly reduce manufacturing costs.

Technical aspects

The objective of this study was to shed light on the technical and economic feasibility of magnesium seats. To take the development and marketing of such seats further, certain technical aspects should now be fully examined. The following are recommendations in that regard:

- Finalize the seat design proposed in the case study (and possibly adopt it for a hybrid solution). Carry out structural analyses required to meet the European ECE 80 standard and to validate possible weight reductions with passenger seats, made of magnesium and/or aluminum, meeting this standard.
- In light of the marketing opportunities, incorporate attachment points for three-point seatbelts into the new design.
- Continue developing the proposed design in close collaboration with experts specializing in the selected casting technologies in order to optimize the seat design, make maximum use of the properties of the selected alloys and accurately determine potential weight savings.
- Optimize the design in order to minimize the overall dimensions of various seat components and improve ergonomic aspects to enhance passenger comfort over long distances.
- To further optimize the proposed design, carry out a comparative and quantitative analysis of the AM60B magnesium alloy typically used in the automobile industry, in addition to new alloys with improved properties, particularly Noranda and Dead Sea Magnesium alloys.
- Conduct collision and corrosion tests on exposed structural components, if necessary, and carry out any other mechanical testing that will help validate the final design.
- Carry out an actual case study with assembled magnesium or hybrid seat prototypes installed in an operating motor coach.

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GLOSSARY OF ACRONYMS AND ABBREVIATIONS

ABA	American Bus Association
ADR	Australian Design Rules
Al	Aluminum
ANPACT	National Association of Bus, Truck and Semi-Trailer Manufacturers (abbreviation represents name of this Mexican organization in Spanish)
APTA	American Public Transportation Association
ASTM	American Society for Testing and Materials
BRT	Bus Rapid Transit
CAFE	Corporate Average Fuel Economy program
CMVSS	Canada Motor Vehicle Safety Standard
CUTA	Canadian Urban Transit Association
ECE	Economic Commission for Europe
EPA	Environmental Protection Agency (USA)
FMVSS	Federal Motor Vehicle Safety Standards (USA)
FTA	Federal Transportation Administration (USA)
G	Acceleration of gravity $g = 9.8\ m/s^2$ (a capital G is used to avoid any confusion with the abbreviation "g" used for gram)
Mg	Magnesium
NAFTA	North American Free Trade Agreement
NFPA	National Fire Protection Association
SAE	Society of Automotive Engineers
TDC	Transportation Development Centre

1. INTRODUCTION

1.1 STUDY OBJECTIVE

This study was conducted for Transport Canada's Transportation Development Centre (TDC) in order to dispel doubts about the use of magnesium to manufacture lighter-weight seats for the public transit industry, particularly the motor coach industry. The study's objective was to validate the feasibility of magnesium seats and propose a plan of action for developing and validating initial prototypes.

Although aluminum solutions were also options taken into consideration in this study, the magnesium solution offered the best scenario in terms of weight reduction and therefore priority was given to determining its viability. It will become clear upon reading this analysis that a range of options is possible: an all-aluminum solution, an all-magnesium solution or a combination of these materials. The final choice will depend on manufacturers' specific objectives and desired compromises in terms of weight reduction, cost reductions, comfort and safety.

Because motor coach seats are more luxurious and expensive than those in urban transit buses and North American manufacturers are receptive to new concepts (unlike the typically more conservative intercity rail industry), the motor coach industry was selected as the first market that could benefit from the introduction of magnesium seats. The issue analysis and the case study therefore focus on this initial target market. However, the study highlights similarities between the motor coach market and the train market, which could be a second target. Once economies of scale are realized, the urban bus target could, in turn, certainly benefit from the expertise developed in the motor coach industry.

The Canadian, American and Mexican markets were looked at within the context of the North American Free Trade Agreement (NAFTA). Data for the Mexican market, however, was more limited.

1.2 METHODOLOGY

IC^2 Technologies Inc, a firm specializing in technology monitoring and development of light metal products, was asked to conduct this study.

The study consisted of the following activities:

- Two case studies carried out by one of the authors in order to develop a magnesium seat for the motor coach and train markets;
- A review of specialized literature and government standards;
- A review of previous bus and motor coach weight-reduction studies carried out for Transport Canada and TDC;
- Gathering of industry data and statistics;
- Interviews with industry representatives, particularly magnesium processors, bus and motor coach manufacturers, seat manufacturers and motor coach fleet operators (intercity and charter);

- Additional tests carried out with certified organizations.

Appendix A includes a list of firms and individuals who were consulted for the purposes of this study.

The following were the objectives of the work plan:

- Draw up a profile of the public transit market in order to identify the North American market for public transit vehicle seats;
- Outline current uses made of magnesium seats, particularly in the automobile industry;
- Identify and describe the key technological and economic issues involved in developing magnesium seats;
- Carry out a cost-benefit study for the manufacturing of magnesium motor coach seats;
- Propose an action plan for developing and marketing magnesium seats.

1.3 BACKGROUND

Lower vehicle weight is recognized for its many benefits and is becoming a major issue in terms of environmental considerations, road safety and emerging new energy sources. The benefits include the following:

- **Lower fuel consumption**: Each 10% reduction in the weight of an intercity motor coach results in a fuel saving of 4% to 5%;
- **Reduction in polluting emissions**: A decrease of 1 kg results in a reduction of 45 kg of CO_2 during the service life of a motor coach;
- **Improved safety**: Lower weight makes braking easier and the force of impact in a collision will be less with lighter vehicles;
- **New energy sources**: Light weight is a key element in promoting the viability of clean new propulsion systems, such as fuel cells;
- **Road durability**: The relationship between axle weight and road pavement damage is typically a fourth order relationship. In other words, a weight that is two times heavier typically produces 16 times more damage [1].

In contrast to the benefits of lower vehicle weight, various developments in vehicle design have resulted in significant weight increases. For example, sources of increased vehicle weight in the urban bus industry include the outfitting of vehicles to carry persons with disabilities, the use of alternative fuels such as natural gas, and emissions control systems. A few sources of increased weight in the motor coach industry are greater vehicle length and number of passengers, enhanced comfort (more comfortable seats, video systems, and noise and vibration reduction devices), and measures to improve safety and reduce emissions.

An increasing amount of research work is being done to reduce the weight of heavy vehicles in both Canada and the United States.

For example, Transport Canada published a study in 1999 that looked at current uses of composite materials in the manufacture of urban buses and noted the best ways of using these materials to reduce bus weight [2]. The objectives of a study launched by Transport Canada in 2000 were to define the problem of motor coach weight and to conduct a technical study of motor coach frames and components in order to identify lighter weight options [3]. This study highlighted the growing importance of the motor coach weight issue, as the following excerpt demonstrates (taken from pages vii, viii and xii):

> *In 1988, a memorandum of understanding (MOU) was developed under the auspices of the Transportation Association of Canada to bring about greater uniformity in provincial regulations regarding vehicle size and weight. Under the MOU, the weight limits of the front, drive, and tag axles were set at 5,550 kg, 9,100 kg, and 6,000 kg, respectively. Surveys revealed that out of a total of 140 observations, 50 percent of the buses had steering axle weights exceeding 5,500 kg. In 1997 the front axle capacity was increased to 7,250 kg. Recent surveys indicate that out of 200 observations, 3 percent of buses had the steering axle over the new regulated limit and 18 percent had a weight on their drive axle exceeding the 9,100 kg limit. Therefore, the weight problem had been regularly identified as exceeding regulatory limits.*
>
> *In addition, there was a growing concern regarding emissions produced by the transportation industry. Based on the total annual mileage of approximately 375 million km, the total fuel used by intercity buses per year is estimated at 110.5 million L. While intercity buses comprise a small part of the overall greenhouse gas (GHG) problem, heavier buses produce more emissions. Canada's commitment to the 1997 Kyoto protocol is to reduce GHG emissions by 6 percent below the 1990 levels, from 2008 and 2012. Reducing intercity bus weight is one approach that can address this problem.*
>
> *A 9 percent bus weight reduction would result in a reduction of approximately 17.7 million kg of CO_2 per year. Over the life of the fleet (15 years), the total reduction in CO_2 would be 266 million kg.*

A second phase of this study was proposed in early 2004. Its objective was to reduce the unloaded vehicle weight of a 45-ft. motor coach by 20% by using an optimized design and high-tech materials for the roof structure and floor framing and other components.

Although seats usually account for only 4% of the weight of a city bus or motor coach, lightweight alternatives can produce substantial savings relatively easily and without major vehicle modifications. This report, part of continuing efforts in that regard, explains how these savings may be achieved.

In the United States, considerable effort has been made to reduce the weight of urban buses. According to the *U.S. Climate Change Technology Program* (an R&D program involving many agencies), the following will be the key R&D objectives in the coming years in the American urban bus industry:

- Meet or exceed emissions standards proposed for bus engines by the Environmental Protection Agency (EPA) by 2007;
- Make non-polluting or almost non-polluting urban buses commercially available by 2015;
- Increase gross passenger capacity (usually between 53 and 88 passengers) to 100 passengers and increase seat capacity of buses with two axles from 43 to 50 by 2006;
- Reduce fuel consumption to 10 mi/gal. (23.5 L/100 km) by 2010;
- By 2015, develop a commercially viable fuel-cell-powered urban bus that meets all the usual operating and maintenance standards at less than twice the cost of a conventional vehicle, and with a marginal capital cost no greater than 50% more than that of conventional buses five years after its entry into the market.

Similarly, the American heavy vehicle industry, in co-operation with various federal agencies, set up the 21st Century Truck Program in April 2000 to support the development and marketing of viable technologies that help to significantly reduce fuel consumption and polluting emissions in trucks and buses [4]. This program includes a special component for urban buses (typically 40-ft. buses), the ultimate objective of which is to triple the mileage (kilometres per litre of fuel) by 2010. In addition to reducing various sources of energy loss (engines, mechanical friction, aerodynamics, power train resistance, etc.), a reduction of more than 20% of vehicle weight is targeted (target weight of 11,158 kg for a 40-ft. urban bus, compared with a typical current weight of 14,515 kg). This weight reduction would help achieve at least 20% of the desired fuel savings.

1.4 DEFINITIONS

The ground public transit industry includes various modes of transportation for moving large numbers of passengers locally, regionally and between cities. Most of these modes of transportation are described below and fall into the two main categories of bus and rail.

Urban bus: A bus designed to carry passengers in urban areas along routes with frequent stops. Most urban buses are 30 or more feet long (typically 40 ft., but may exceed 60 ft. in the case of articulated buses), have 30 or more seats (low back) and can accommodate standing passengers. They have front and rear doors, no luggage compartment and no lavatory. They are operated by public transit authorities.

Trolley bus: A wheeled vehicle similar to a bus, but equipped with an electric motor powered by a cable running along overhead electrical wires. These are operated by public transit authorities.

Minibus: A vehicle usually 20 to 25 ft. long (15 to 20 seats) and typically used to provide shuttle services (airports, hotels, tourism services, etc.). Minibuses are usually operated by private-sector firms. They are also often used to provide urban transportation services in small municipalities.

Suburban bus: A bus midway between a conventional urban bus and a motor coach. Suburban buses are 40-ft. or 45-ft. vehicles in which all passengers are seated (seats have high backs, compared with the low-back seats of urban buses). They have a single door at the front, no luggage compartment or lavatory, and are used for trips between the city and suburbs with relatively few stops. Suburban buses provide a little more comfort than urban buses, but not the level of comfort of deluxe motor coaches. They are usually operated by a public transit authority.

Motor coach: A relatively deluxe bus designed to carry passengers over long distances. Although designed for intercity transportation, motor coaches are also used for charter trips and tourism-related services. The vehicles have a raised floor located above the luggage compartments. They are at least 35 ft. long and can seat more than 30 passengers. Typical motor coaches are 40 ft. to 45 ft. long and have 45 to 58 seats with high backs. They are usually operated by private-sector firms.

Heavy-rail train: An underground, surface or high-speed electric train consisting of several cars and used in urban areas to move large numbers of passengers. Subways are operated by public transit authorities.

Light-rail train: A small urban train of the streetcar or trolley type (typically one or two cars), usually equipped with an electric motor powered by a cable running along overhead wires. These are operated by public transit authorities.

Commuter train: A train designed to carry passengers between the city core and the suburbs. Commuter trains can be diesel or electrically powered. They are operated by public transit authorities.

Intercity train: A more deluxe train, usually diesel-powered and designed to carry passengers over long distances. Operated by national passenger railway companies, such as VIA Rail in Canada and Amtrak in the United States, and by some regional operators.

N.B.: Although from a technical point of view, urban and suburban buses have different designs, the available statistical data usually do not make a distinction between them. Consequently, these two categories are combined in the statistics that follow.

2. REVIEW OF THE MARKET, MANUFACTURERS AND CURRENT APPLICATIONS

This section provides an overview of the ground public transit industry, including major industry players and changes that have occurred in public transit vehicle markets. Special attention is devoted to the motor coach market. There is also an overview of the passenger seat market and profiles of the principal seat manufacturers. The section concludes with brief descriptions of the current applications for magnesium seats.

2.1 NORTH AMERICAN PUBLIC TRANSIT MARKET

2.1.1 Overview of North American public transit

In Canada and the United States, there are some 160,000 vehicles in service (buses and train cars of all types) and some 6,400 operators (public transit authorities or private-sector firms) providing passengers with urban and intercity transportation services. The United States market alone accounts for 85% of the vehicles in service and 92% of the operators. Tables 1 and 2 provide an overview of these markets.

If intercity transit services by motor coach are excluded, the United States and Canada have seen moderate overall growth in recent years (from 1997 to 2002) in the use of various public transit options involving trains or buses. The growth has averaged between 1.5% and 3.5% per year, depending on the mode of transportation (see Figure 1). However, average growth in some segments of the market has exceeded 10% in recent years. For example, the number of passengers on commuter trains in Montreal, Toronto and Vancouver rose from 21 million in 1994 to over 50 million in 2002.

Passenger volume in the United States motor coach industry remained relatively unchanged between 1988 and 1997, while in Canada, passenger volume fell by 40% between 1988 and 1993 and then remained stable up to 1997 (see Figure 2). Since 1999, the motor coach industry has been going through a relatively difficult period in both Canada and the United States. There has been a significant drop in ridership and sales; major operators' fleets have been greatly reduced in size; and fewer new vehicles have been purchased. Nonetheless, motor coaches continue to be a major passenger carrier in North America, surpassing airplanes and trains.

Table 1. Overview of the United States Ground Public Transit Market

Mode of Transportation	Number of Operators	Number of Vehicles or Cars in Use	Annual Capital Investment* (millions of US$)
Urban Transit			
Urban bus	2,264	76,000	2,049
Heavy-rail train	14	10,700	985
Light-rail train	26	1,300	244
Commuter train	21	5,100	484
Intercity Transit			
Motor coach	3,600	40,000	N/A
Intercity train	1**	2,140	200

* Direct investment in vehicle acquisition, refurbishing and acquisition of major parts.

** Amtrak is the only national operator and accounts for some 95% of passenger transport by rail in the United States.

Sources: APTA (2002 data), ABA and Amtrak

Table 2. Overview of Canada's Ground Public Transit Market

Mode of Transportation	Number of Operators	Number of Vehicles or Cars in Use	Annual Capital Investment* (millions of $)
Urban Transit			
Urban bus	91	12,000	530
Heavy-rail train		1,450	
Light-rail train		600	
Commuter train		580	
Intercity Transit			
Motor coach	400	4,000	N/A
Intercity train	1 **	470	N/A

* Direct investment in vehicle acquisition, rehabilitation and acquisition of major parts.

** There is only one operator of 1st class services (VIA Rail) and a few regional operators of 2nd class services, which account for less than 1% of passengers transported by rail in Canada.

Sources: CUTA (2002 data), ABA and VIA Rail

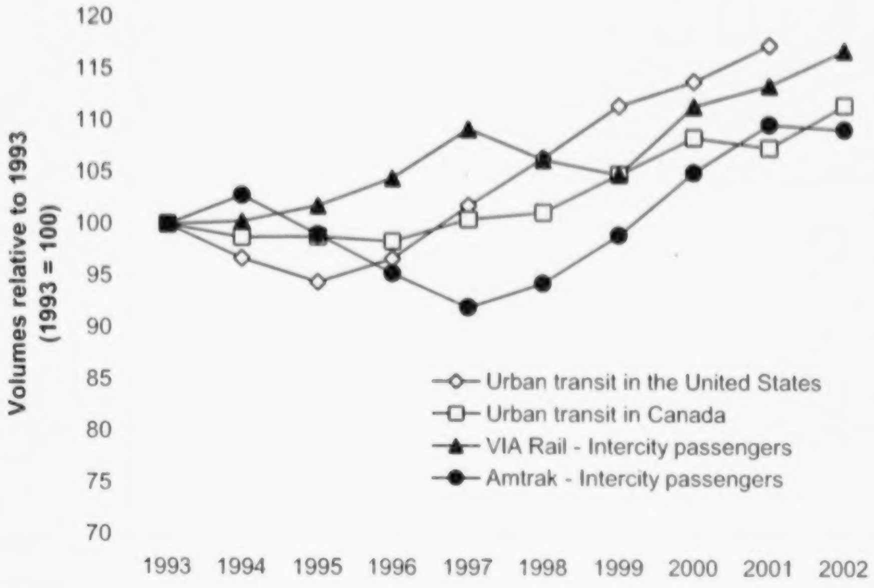

Figure 1. Volume of Passengers Using Urban Transit (Buses and Trains) and Intercity Rail, 1993–2002

Sources: APTA, ACTU, VIA Rail and Congressional Budget Office

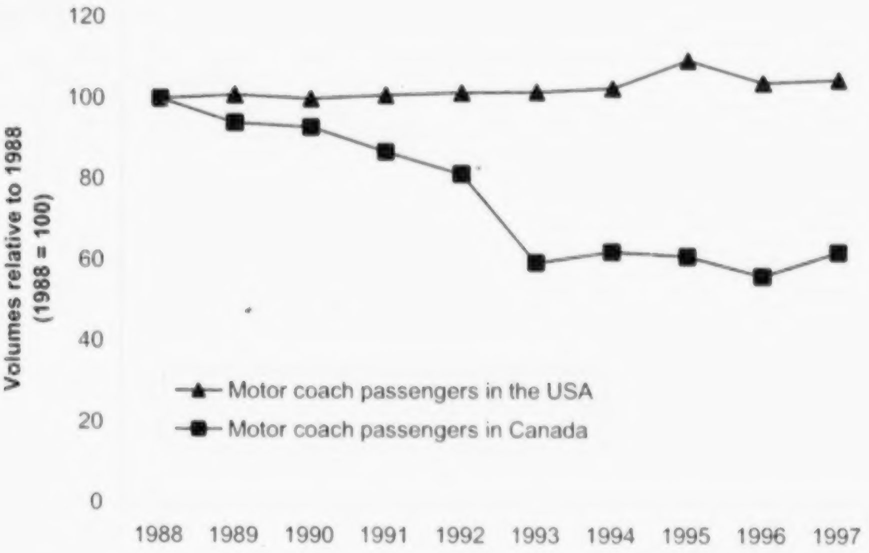

Figure 2. Volume of Passengers Using Intercity Motor Coach Transit, 1988–1997

Source: Transport Canada, based on data from Statistics Canada, Royal Commission on National Passenger Transportation and Eno Transportation Foundation

There has also been a significant increase in government investment to improve and develop urban public transit infrastructure, particularly in the United States. In May 1998, the United States Congress passed the *Transportation Equity Act for the 21st Century* (TEA 21) and allocated US$42 billion for overall public transit development up to 2003. The Bush administration is currently working on a new program that may allocate some US$69 billion over the next six years.

In the United States and Canada, there are currently 43 investment projects, each involving more than $100 million, in the urban train sector alone (heavy rail, light rail and commuter rail). The 10 biggest involve a total investment of nearly US$38 billion. Significant investments are also being made in the intercity rail sector, with Amtrak investing about US$1 billion in projects over the next five years and VIA Rail planning to invest a total of $1 billion in the 2000–2008 period.

2.1.2 Urban buses

The main urban bus market clients are public transit authorities and corporations in various North American municipalities. In 2002, the Canadian/American urban bus fleet consisted of an estimated 88,000 vehicles, of which some 76,000 were in the United States and some 12,000 in Canada. In Mexico, the urban bus fleet comprised about 90,000 vehicles, but most of these were minibuses and buses under 30 ft. in length.

According to APTA data (see Figure 3), about 4,800 new buses were acquired in the American market in 2002, as follows:

- 16% in the ≤ 29-seat category;
- 40% in the 30–39-seat category;
- 44% in the ≥ 40-seat category.

Articulated or double-deck buses (typically 60 to 80 seats) accounted for 4% of new acquisitions.

The average annual number of vehicles acquired in the past 10 years in the United States was about 4,600 units. According to the ACTU data for Canada (see Figure 4), about 460 buses were acquired in 2002, compared with the 10-year average of about 400 units.

According to data from Volvo Bus of Mexico, the Mexican market for all categories of urban buses amounted to 6,400 units in 2003. The average number of units sold in the past five years was 7,300. However, this market has a large number of buses under 30 ft. in length. The estimated current market share for new urban buses over 30 ft. in length is about 40%, or 2,500 units per year. This share is likely to increase over the next few years because the Mexican government hopes to replace a large number of small buses currently used in major cities with larger buses, and the production of minibuses will be prohibited.

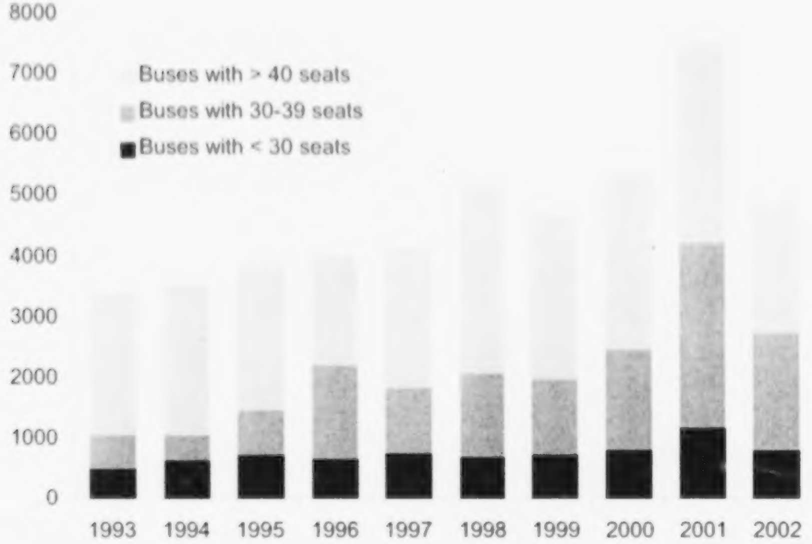

Figure 3. Annual Sales of Urban Buses in the United States (Units Sold)

Source: APTA

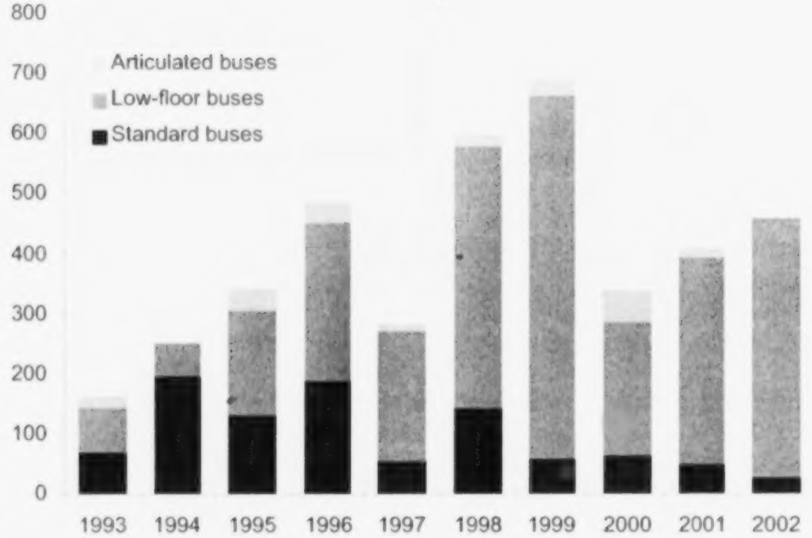

Figure 4. Annual Sales of Urban Buses in Canada (Units Sold)

Source: ACTU

Table 3 provides an overview of urban bus manufacturers (buses 30 or more feet in length) in the Canadian/American market. The Van Hool Corporation of Belgium, which exports some of its vehicles to Canadian and American markets, is also mentioned, as is motor coach market leader Motor Coach Industries, which also manufactures commuter and intercity buses tailored to metropolitan transit authority requirements. Figure 5 provides an overview of vehicles built in 2002 for the American market, with a breakdown by manufacturer.

Table 3. Principal Urban Bus Manufacturers for the Canadian/American Market (Buses 30 or More Feet in Length)

Manufacturer	Head Office	Plants	Products	Estimated Number of Units Sold Per Year
New Flyer Industries www.newflyer.com	Manitoba	• Manitoba • Minnesota (2)	5 low-floor models varying from 30' (25 seats) to 60' articulated (64 seats)	1,100
Nova Bus (Prévost Car) www.novabus.com	Quebec City	• Quebec City (2)	1 40' low-floor model (38 seats)	450
Orion Bus Industries (DaimlerChrysler Commercial Buses North America) www.orionbus.com	North Carolina	• Ontario • New York	10 low-floor and high-floor models varying from 29' to 40' (20 to 45 seats)	700–900
NABI – North American Bus Industries www.nabiusa.com	Parent company NABI Rt based in Hungary	• Alabama (2) • Hungary	8 low-floor and high-floor models varying from 30' to 40' (26 to 65 seats)	850
Gillig www.gillig.com	California	• California	6 low-floor and high-floor models varying from 29' to 40' (28 to 45 seats)	1,200
Neoplan USA www.neoplanusa.com	Colorado	• Colorado	7 low-floor and high-floor models varying from 35' to 60' articulated (37 to 65 seats)	250–450
Blue Bird (Henlys Group) www.blue-bird.com	Georgia	• Georgia	6 low-floor and high-floor models varying from 28' to 40' (27 to 49 seats)	50–100

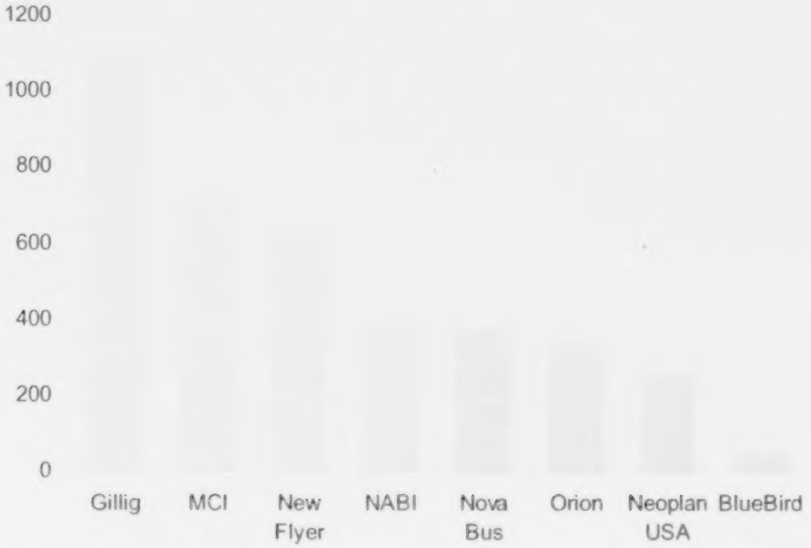

Figure 5. Urban Buses Manufactured for the American Market in 2002, by Manufacturer (Manufactured Units)

Source: APTA, based on partial data

Development of Bus Rapid Transit (BRT)

Worth noting is the emergence and growing interest in bus rapid transit, or BRT. It is defined as rapid public transit, based on buses, that uses dedicated rights of way and stations in the same way as light-rail trains and streetcars. In the United States, the Federal Transportation Administration (FTA) defines BRT as a rapid mode of transportation combining the qualities of urban rail and the flexibility of buses. BRT systems are considered a less costly alternative to urban rail development, an alternative to building new expressways and a catalyst for urban development. BRT is also seen as a way to enhance the image of public transit, particularly in North America.

BRT is mainly used in large urban centres with more than 1 million residents and a major concentration of jobs in the downtown core. The main characteristics of BRT typically include special lanes, attractive stations, distinctive, easy-to-board vehicles, a fare-collection system outside the vehicle, the use of intelligent transportation technologies, and frequent service all day long. Although other factors are considered more important or a priority, passenger comfort is also one of the considerations usually selected for the design of new BRT vehicles. However, cost and service life are major concerns.

2.1.3 Urban trains

As with urban buses, the principal urban train market clients (heavy rail, light rail [e.g., streetcars] and commuter rail) are public transit corporations and authorities in major North American urban centres. In 2002, the estimated Canadian/American fleet of train cars in all categories amounted to nearly 20,000 units, of which some 17,000 were in the United States and some 2,600 in Canada.

According to APTA, about 950 passenger cars were built for the American market in 2002, as follows:

- 21% in the < 40 seat category;
- 46% in the 40–49 seat category;
- 14% in the 50–74 seat category;
- 1.5% in the 75–99 seat category;
- 14% in the 100–129 seat category;
- 3% in the 130+ seat category.

In Canada, only 21 cars, all in the light-rail train category, were acquired in 2002. However, the number of vehicles acquired over the previous five years was closer to 80 per year (see Figure 7) and were mostly in the subway car category.

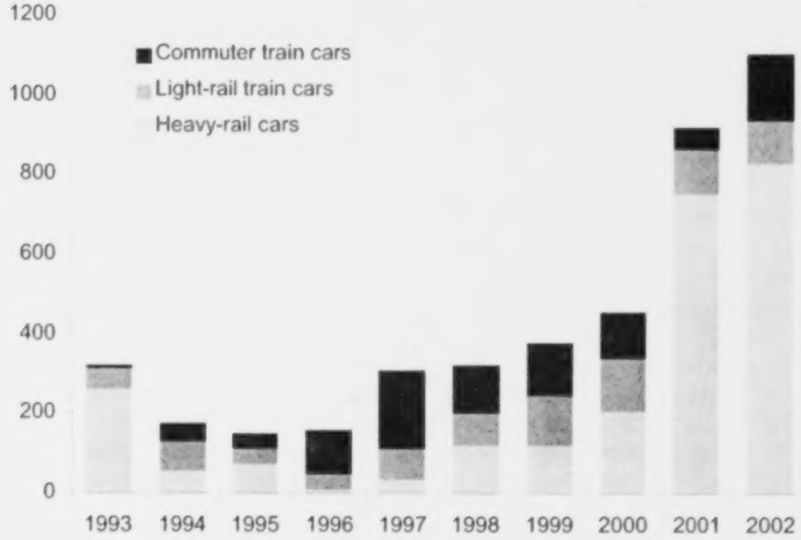

Figure 6. Annual Sales of Urban Train Passenger Cars in the United States (Units Sold)

Source: APTA

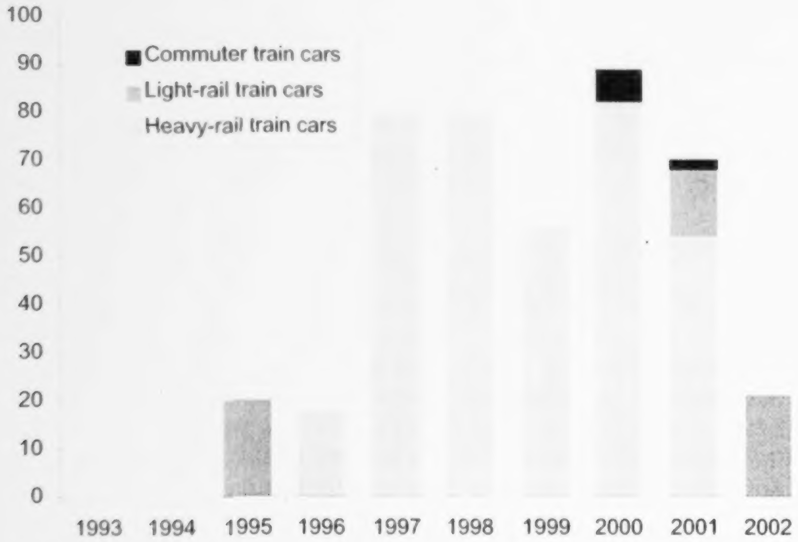

Figure 7. Annual Sales of Urban Train Passenger Cars in Canada (Units Sold)

Source: ACTU

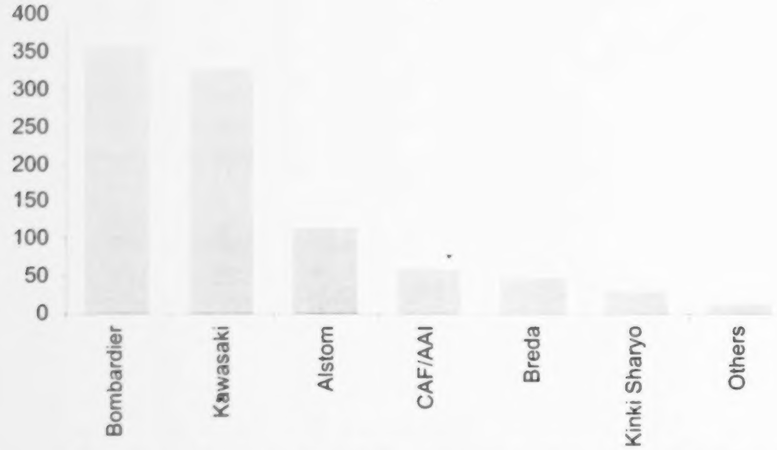

Figure 8. Number of Urban Train Cars Manufactured for the American Market in 2002, by Manufacturer (Manufactured Units)

Source: APTA

Figure 8 provides an overview, broken down by manufacturer, of the number of vehicles manufactured for the American market in 2002. The following are some of the major builders of passenger cars for North American urban trains (manufacturers of heavy-rail, light-rail and commuter rail cars):

- Alstom (New York, NY)
- Bombardier Transportation (St. Bruno, QC)

- Siemens Transportation Systems (Sacramento, CA)
- Kawasaki Rail Car (Yonkers, NY)
- Breda Transportation (New York, NY)
- CAF USA (Washington, DC)
- Colorado Railcar Manufacturing (Ft. Lupton, CO)
- Nippon Sharyo USA (New York, NY)

In terms of major clients, the City of New York Metropolitan Transportation Authority alone accounts for over 35% of the United States urban train fleet. When the Long Island Railroad and Metro-North Railroad authorities are included, close to 50% of the American fleet can be found in this region (see Table 4).

According to the *METRO* magazine annual survey, the City of New York Metropolitan Transportation Authority, with projects totalling US$9 billion, once again topped the list of the biggest investment projects for developing urban rail in 2003. The only Canadian cities on the list of the 50 biggest North American projects were Montreal in 37th place ($345 million) and Calgary in 42nd place ($163 million).

Table 4. Canadian/American Market's Ten Biggest Urban Train Operators

Transportation Authority	Number of Vehicles
MTA New York City Transit	6,348
Chicago Transit Authority	1,218
Massachusetts Bay Transportation Authority	1,054
New Jersey Transit	1,037
MTA Long Island Railroad	976
MTA Metro-North Railroad (New York)	944
Metra Commuter Rail (Northeast Illinois)	910
Washington Metropolitan Area Transit Authority	892
Southeastern Pennsylvania Transportation Authority	869

Source: *METRO* Magazine, June-July 2003

2.1.4 Intercity trains

The intercity passenger train network is managed almost entirely (over 95%) by two major national corporations, VIA Rail in Canada and Amtrak in the United States (there is almost no passenger rail transportation in Mexico). The total Canadian/American passenger car fleet contains some 2,610 units, of which 2,140 belong to Amtrak and 470 to VIA Rail. A typical coach car can seat between 40 and 80 passengers and sometimes up to more than 100 passengers (passenger cars also include sleeping cars and service coaches).

Major investments have been made in intercity passenger rail transportation in Canada since 2000. In fact, Transport Canada announced a capital funding program for VIA Rail in October 2003. The Renaissance II Program, with a budget of $692.5 million over five years, seeks to continue the work of revitalizing Canada's intercity passenger rail services. Combined with the initial phase of the Program announced in April 2000, which was allocated a budget of nearly $402 million, close to $1 billion has been invested in rolling stock and infrastructure. In 2000, as part of its Renaissance Program, VIA Rail acquired its largest number of vehicles in 20 years when it purchased about 100 passenger cars (manufactured by Alstom), which increased the size of its fleet by a third. The Corporation also carried out interior renovations in its VIA 1 Class cars and LRC cars. With the announcement that the investment program would be extended, VIA Rail will continue renewing and refurbishing its fleet.

In the United States, Amtrak, in accordance with its 2004–2008 strategic plan, hopes to minimize its investments in new car acquisitions by renovating a greater number of existing cars to extend their service lives, and intends to standardize more of its fleet. The Corporation plans to invest about US$1 billion in capital assets (acquisitions and renovations) for its passenger car fleet over the next five years. According to company data, Amtrak plans to acquire some 90 passenger cars and renovate over 800 cars during this period.

The following are the principal manufacturers of passenger cars for VIA Rail and Amtrak:

- Alstom (New York, NY)
- Bombardier Transportation (St. Bruno, QC)
- Siemens Transportation Systems (Sacramento, CA)
- Talgo Rail (Seattle, WA)

2.1.5 Motor coaches

Motor coaches are usually operated by private-sector firms and are a major component of the North American transportation system. For example, according to the American Bus Association, motor coaches (intercity, charter and tourist) carried about 774 million passengers in the United States in 1999, compared with 568 million carried by airlines and 377 million carried by railway companies.

According to a study published in 2000 by R L Banks & Associates for the American Bus Association, there were some 40,000 motor coaches in use in the United States and

4,000 in Canada to meet the travel requirements of some 860 million passengers each year.

Mexico is also a major motor coach market as well as an interesting target for expansion for Canadian and American manufacturers. Between 30,000 and 40,000 motor coaches are in use in Mexico to provide intercity services. In fact, motor coaches provide over 97% of intercity public transportation in Mexico because the passenger rail system is practically non-existent and air transportation is very costly. According to Volvo Bus of Mexico, about 50% of Mexican motor coaches are economy class, 42% are first class and 8% are executive class.

In terms of fleet operators, there are some 3,600 in the United States and 400 in Canada, of which nearly 90% have fleets of fewer than 25 vehicles and 75% have fleets of fewer than 10 vehicles. The 50 biggest operators (in terms of vehicles in service) account for about 30% of the North American motor coach market (the two biggest operators in 2003 were Coach USA and Greyhound Lines, operating a total of about 5,000 vehicles; however, Coach USA is currently undergoing a major restructuring, including the dismantling of part of its network). Table 5 is an overview of the 10 biggest motor coach carriers in 2003. In terms of market share, Greyhound (owned by Laidlaw International) is the biggest intercity motor coach carrier in both Canada and the United States.

Motor coach sales in the United States and Canada totalled 2,400 units in 2002 and 1,770 units in 2003 (or more specifically, 1,624 in the United States and 147 in Canada), according to *National Bus Trader Magazine* (data taken from a survey of manufacturers). As shown in Figure 9, the market has been steadily decreasing since 1999 (a cumulative drop of about 50%) after posting strong growth in the 1990s. According to *National Bus Trader Magazine*, the typical average number of motor coaches sold per year in the United States and Canada in recent decades was between 1,000 and 1,500. The main reasons for the boom of the 1990s (up to 3,600 units in 1998) were a strong economy and switchovers to 45-ft. models. Consequently, the 2003 sales were closer to the long-term normal level and average, according to *National Bus Trader Magazine*. However, the authors of another study, *The World Bus & Coach Manufacturing Industry* [5], believe that annual sales should return to a level between 2,800 and 3,200 units in the 2004–2007 period.

In Mexico, motor coach sales totalled about 1,900 units in 2003, which was the average number for the previous five years (Indicador Automotriz, February 2004, and Volvo Bus of Mexico). The Mexican market posted strong growth between 1999 and 2001, with numbers of units rising from 1,200 to 2,800, and later falling to between 1,800 and 1,900 in 2002 and 2003. Note that Mexico's market is as big as that of Canada and the United States combined.

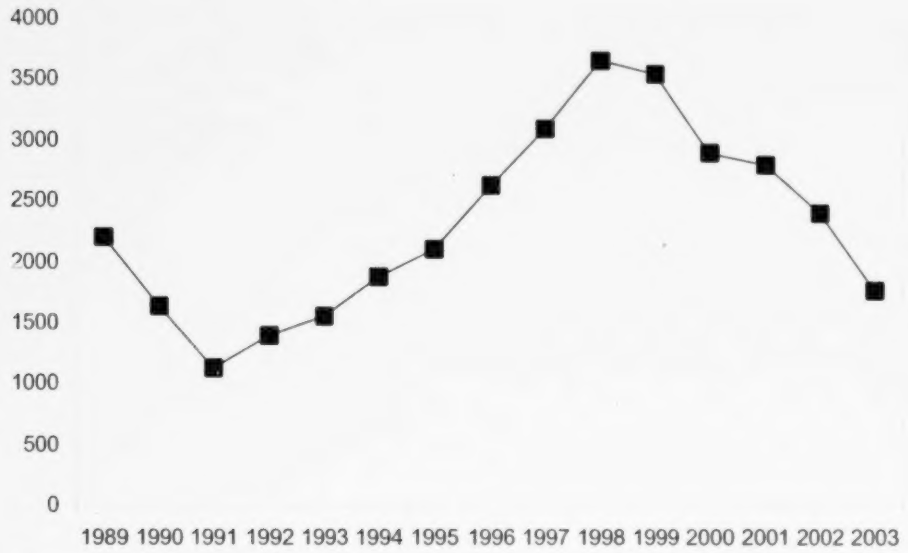

Figure 9. Motor Coach Sales in the United States and Canada, 1989–2003

Source: *National Bus Trader Magazine*, March 2004

According to the most recent *METRO* magazine survey, the most active operators in the past year in terms of vehicle acquisitions were Peter Pan Bus Lines, which increased its fleet from 135 to 343 motor coaches, and Orléans Express, which increased its number of motor coaches from 68 to 122 (now in 20th place among carriers).

Table 5. Ten Biggest Motor Coach Carriers in the Canadian/American Market

Company	Head Office	Number of Motor Coaches
Coach USA	Houston, TX	2,727
Greyhound Lines	Dallas, TX	2,300
Academy Bus	Hoboken, NJ	704
Pacific Western Transportation	Toronto, ON	519
Liberty Lines	Yonkers, NY	411
Roberts Hawaii Tours	Honolulu, HI	394
Peter Pan Bus Lines	Springfield, MA	343
Holland America Line	Seattle, WA	314
Queens Surface	Flushing, NY	313
Martz Group	Wilkes Barre, PA	297

Source: *METRO* Magazine, January 2004

Motor coach manufacturers

Table 6 provides an overview of motor coach manufacturers with operations in North America. There are now three manufacturers with operations in Canada and the United States (of which MCI and Prévost Car are the biggest), two foreign manufacturers distributing their products in the Canadian/American market, and six manufacturers with operations in Mexico. There are also European manufacturers, such as Mercedes-Benz, Scania, MAN and others, that affiliate with local bus body manufacturers in order to sell their chassis in the North American market, particularly the Mexican market (e.g., the Scania-Busscar alliance).

Table 6. Principal Motor Coach Manufacturers for the North American Market

Manufacturer	Head Office	Plants	Products	Estimated Number of Units Sold Per Year*
Motor coaches for the Canadian/American market				
Motor Coach Industries (MCI) www.mcicoach.com 1-866-624-2622	Illinois, United States	• Manitoba • North Dakota	6 models: E/J/G/D4500 45' (56 seats) D4000 40' (47 seats) F3500 35' (36 seats)	1,000–1,500
Prévost Car (Henlys Group and Volvo Bus) www.prevostcar.com (418) 883-3391	Quebec, Canada	• Quebec (2)	3 models: Mirage XLII 45' (55 seats) H Series, 41' and 45' (48 and 58 seats)	150–300
Blue Bird (Henlys Group) www.blue-bird.com 1-800-486-7122	Georgia, United States	• Georgia	1 model: Express 4500 45' (55 seats)	< 50
Motor coaches sold in North America, but manufactured abroad				
Van Hool www.vanhool.be +32 3 420 20 20 Distributed by: ABC Bus Companies Minnesota, USA www.abc-bus.com 1-800-222-2871	Belgium	• Belgium	2 models: C2000 Series, 45' (57 seats) T2100 Series, 45' (57 seats)	150–300
Setra North America (DaimlerChrysler Commercial Buses North America) www.setra-coaches.com 1-800-882-8054	North Carolina, United States	• Germany	3 models: S215 40' (44-51 seats) S217 45' (52-59 seats) S417 45' (58 seats)	50–100
Motor coaches for the Mexican market				
Volvo Bus Corporation www.volvo.com/bus Mexico: +52 (55) 58 64 37 74	Sweden	Volvo Bus of Mexico • Mexico	3 models: Volvo 7350, 11.6 m Volvo 9300, 12.15 m Volvo 9700, 12.9/13.7 m	600–800

Marcopolo S.A. www.marcopolo.com.br +55 (54) 209-4000 Mexico: +52 (81) 8130-2300	Brazil	• Brazil Polomex • Mexico	8 models: Paradiso Series, 45' (42-56 seats) Andare Class, 43' (50 seats) Allegro, 43' (53 seats) MP120, 43' (54 seats) Multego, 41' (54 seats) Viaggio, 41' (49 seats)	N/A
Busscar Onibus S.A. www.busscar.com.br +55 (47) 441-1133 Mexico: +52 (44) 99 71 01 33	Brazil	• Mexico • Brazil		400–500
Irizar Group www.irizar.com +34 943 80 91 00 Mexico: +52 (442) 238 25 00	Spain	Irizar México • Mexico	2 product lines: Century InterCentury	400–600
Comil Onibus S.A. www.comilonibus.com.br +55 (54) 520-8700	Brazil	• Brazil • Mexico	5 models in the Campione line: 4.05, 3.85, 3.65, 3.45 and 3.25	< 250

[*] Note that sales have fluctuated considerably in recent years following a marked slowdown in the market.

Canada and the United States

- **Motor Coach Industries (MCI)** was founded in Winnipeg, Manitoba, in the early 1930s. After its acquisition by Mexican motor coach manufacturer Grupo Dina in 1994, control was transferred in 1999 to a New York investment firm. MCI operated a Mexican division at Sahagun until early 2003. Its manufacturing operations are now centralized at its Winnipeg, Manitoba, plant, while final assembly and finishing operations for its D Series models are carried out at a second plant located in Pembina, North Dakota. Nowadays, MCI is still the leader in the North American motor coach market, with more than a 50% market, share. In June 2003, MCI announced delivery of its first hybrid diesel-electric motor coach (modified version of the D4000 model) to the New Jersey Transit Authority.
- **Prévost Car** is the second largest motor coach manufacturer for the Canadian/American market after MCI. Since 1995, the company has been owned by Volvo Bus Corporation of Sweden and Henlys PLC of the United Kingdom. The firm has two manufacturing and assembly plants in St. Claire, Quebec, and a parts-cutting plant in St. Anselme, Quebec.
- **Blue Bird** is primarily known for its school buses and has a 40% share of the North American school bus market. The company launched its sole motor coach model, the Express 4500, on the American market in February 2003. Blue Bird's motor coach division (currently producing mainly chassis for the recreational vehicle market) accounts for only 6% of its sales. The firm is 100% owned by Henlys, which is also a joint shareholder in Prévost Car.
- **Van Hool** of Belgium conducts most of its business in Western Europe and Northern Africa. It manufactures about 1,750 buses and motor coaches per year. Because of an exclusive distribution agreement with ABC Bus in the United States (of which Van

Hool is a minority shareholder), Van Hool has become the third largest motor coach supplier in the Canadian/American market after MCI and Prévost. Van Hool's sales in the North American market have risen to as high as 600 motor coaches per year.

- **Setra North America** is a division of the DaimlerChrysler Commercial Buses of North America group, which also owns Orion Bus Industries, which specializes in urban buses, and Thomas Dennis Buses (now fully incorporated into the DaimlerChrysler Commercial Buses brand). Setra North America is responsible for sales and customer service in the United States and Canada for Setra vehicles manufactured in Germany. In Europe, Setra is part of EvoBus, a DaimlerChrysler subsidiary. In 2003, Setra introduced its latest model, the S417, which posted an excellent performance in its first year.
- **Neoplan USA** used to have six motor coach models in its product line for the North American market. But following a change of ownership, the company pulled out of the motor coach market in 2003 and is now concentrating on the urban bus market.

Based on the annual *National Bus Trader Magazine* survey, Table 7 shows the most popular models in Canada and the United States in 2003. One of the trends observed in the Canadian/American market is that close to 94% of the models sold are now 43-ft. or 45-foot. With the introduction of the Setra S417, all models are now in the 112-in. width category. The market share for imported models (Setra and Van Hool) increased during the 1992–2000 period to a record 22.5%, then fell sharply in 2002 to 12.6%. After the Setra S417 model was introduced in 2003, the market share for imported models in the Canada and the United States rose to 18.4%.

Table 7. Most Popular Motor Coach Models in the Canadian/American Market in 2003

Brand and Model	
1.	MCI D4500
2.	MCI J4500
3.	Van Hool C2045
4.	Setra S417
5.	Prévost H3-45
6.	MCI G4500
7.	MCI E4500

Source: *National Bus Trader Magazine*, March 2004

Mexico

- **Volvo Bus Corporation** entered the Mexican market in 1998 when it acquired Mexicana de Autobuses, known as MASA. Although the priority is to meet the requirements of the Mexican market, the company's products can meet the requirements of American clients; therefore, Volvo Bus may also consider breaking into Prévost Car's separate American niche markets (*Bus Ride Magazine*, April 2003). The motor coach division accounts for about 23% of Volvo Bus of Mexico's sales, and the company has about a 44% share of the Mexican market. Volvo Bus Corporation is the world's second largest bus manufacturer.

- **Marcopolo**, with a market share of about 50%, is the biggest motor coach manufacturer in Brazil. Its motor coaches are mounted on Volvo, Mercedes-Benz, Scania or Volkswagen chassis. Motor coach manufacturing accounts for 37% of the company's sales of about 3,000 units per year. Marcopolo began exporting to Mexico in 1992 in a partnership with Dina Corporation, which marketed the Dina Viaggio model. In 1994, after the MCI-Dina merger, MCI introduced the Dina Viaggio model into the United States. Since 2000, Marcopolo has formed an alliance with Mercedes-Benz Mexico, which owns 26% of the Mexican subsidiary Polomex SA de CV. This plant has a capacity of 5,000 vehicles per year (urban buses and motor coaches) and targets markets in North America, Central America and the Caribbean (products marketed under the Marcopolo and Mercedes-Benz brand).
- **Busscar** is Brazil's second biggest manufacturer of buses and motor coaches. The firm has plants in Mexico and Venezuela and joint ventures in Colombia, Cuba and Norway. Busscar produces some 5,500 bus bodies per year (urban buses and motor coaches), of which close to 30% are exported (North America, Europe and Africa). The firm assembles its buses on Scania, Volvo and Mercedes-Benz chassis. The Mexican market, where Busscar is allied with Scania, accounted for up to 20% of its sales (the Mexican plant is currently undergoing a restructuring and a significant decrease in production). Busscar now hopes to break into American and Canadian markets, where it has been allied with MCI since 2001 to develop design models. (Some urban products were introduced in 2003).
- The objective of the Mexican subsidiary of **Irizar**, set up in 1999, is to carve out a 30% share of the Mexican market. The Mexican plant has a production capacity of 500 units per year and is planning to possibly expand to 1,000 units. Its bus bodies are mounted on Scania, Mercedes-Benz and MAN chassis. The Mexican subsidiary also hopes to benefit from NAFTA and develop its exports to American and Canadian markets. Irizar is the second biggest motor coach manufacturer in Europe and has operations in 65 countries.
- **Comil**, a major bus manufacturer in Brazil, produces about 600 motor coaches per year. The firm has operations in many markets in Central America, South America, Africa, the Caribbean and Mexico. Exports (urban buses and motor coaches) account for nearly 40% of its sales. Comil's new Mexican plant produces the Campione line of motor coaches from bus bodies that it builds in its Brazilian facilities and assembles with locally manufactured chassis. Comil used to assemble its bus bodies for urban and intercity models at the Volvo Bus of Mexico and Scania facilities.

2.2 PASSENGER SEAT MARKET ASSESSMENT

N.B.: In Table 8, a seat corresponds to a seat for one passenger. For the time being, the fact that, technically speaking, seats are usually double seats, or more than double seats in the case of urban buses, has not been taken into consideration.

Table 8. Estimated North American Market for New Seats in the Ground Public Transit Industry (New Vehicles)

	Urban Buses	Motor Coaches	Urban Trains	Intercity Trains
	Usual Number of Seats per Vehicle			
	40	50	56	60
	Projected Annual Market for New Vehicles			
Canada	400	150	80	N/A
United States	4,600	1,350	630	N/A
Mexico	2,500	1,900	N/A	---
	Estimated Number of New Seats			
Canada	15,000	7,500	5,000	N/A
United States	185,000	67,500	35,000	N/A
Mexico	100,000	95,000	N/A	---
Total	**300,000**	**170,000**	**40,000**	**N/A**
	Typical Price per Double Seat (Original Seat)			
	$400–$500	$700–$2,000	Heavy-rail and light-rail trains: $450–$900 Commuter trains: $900–$2,000	$1,000–$3,000

Table 8 shows a summary of the data used in the previous section to assess the size of the passenger seat market for various types of ground public transit.

The projected requirement for the urban bus market is an average of 4,600 new buses per year in the United States, 400 in Canada and 2,500 in Mexico. If the average number of seats per bus is 40, based on a breakdown of typical sales in 2002, the estimated average annual requirement for new urban bus seats would be some 185,000 units in the United States, 15,000 units in Canada and 100,000 units in Mexico.

The projected requirement for the urban train market (heavy-rail trains, light-rail trains and commuter trains) is an average of 56 seats per passenger car (based on 2002 sales), using a conservative average of 630 cars in the United States (based on new acquisitions over the previous five years) and usually fewer than 80 cars in Canada. The average annual market in the United States can therefore be estimated to be some 35,000 units (with numbers of passenger seats exceeding 50,000 units in the past two years) and usually fewer than 5,000 units per year in the Canadian market.

The projected requirement for motor coaches is usually 1,500 vehicles on average per year for the Canadian/American market (90% in the United States and 10% in Canada) and an average of 50 seats per vehicle. For Mexico, it is an average of 1,900 vehicles. This estimated North American market for passenger seats is therefore some 170,000 units per year.

The above estimates only take the new vehicle market into account. The vehicle-refurbishing sector is also a market for passenger seats (especially in the railway industry).

In addition to numbers of seats, it is important to take into account various seat types and selling prices in each market.

Seats for urban buses, heavy-rail trains and light-rail trains are usually economically priced seats consisting of fibreglass-reinforced, plastic moulded shells, cushion inserts and steel frames. These seats are not adjustable and provide a minimum of comfort for short trips (seats with low backs). The urban bus segment of the market, although high volume, is a product entry level market where selling prices are lower. Nonetheless, the prices are still fairly high (about $400 to $500 for a double seat) because of the variety of seat configurations in a bus and from one vehicle to another (single seats, double seats, row seats, seats above wheels, seats behind the engine compartment, etc.) for which economies of scale are difficult to obtain.

Conversely, motor coach and intercity train seats are designed more for passenger comfort over longer distances. These more ample, high-end seats are upholstered and have high seatbacks, headrests and armrests. The seat frames are usually made of pressed steel. In some cases, parts of the frames are made of extruded aluminum. The price range is fairly broad – $600 to $700 per double seat in the economy category and up to $2,000 or more for a high-end double seat.

2.3 PRINCIPAL PUBLIC TRANSIT SEAT MANUFACTURERS

Table 9 provides an overview of North American passenger seat manufacturers for the bus and train industry. In addition to these specialized seat manufacturers, some bus manufacturers manufacture their own seats (e.g., Setra and Van Hool) or include their own seat lines with those offered by their suppliers (e.g., Prévost Car and Busscar).

Clients usually select seats (in over 80% of cases). In most cases, style is the main differentiating factor. In North America, weight reduction concerns do not yet appear to have had a pronounced impact on the products of the principal manufacturers. However, some seat manufacturers pointed out during the survey that they were interested in lighter-weight seats, but at competitive prices. Because the importance of lower weight varies considerably from one operator to another, lower weight is not always a good selling point for seat manufacturers, unless lower weight has no negative impact on price. A motor coach seat usually weighs between 35 kg and 40 kg. Several manufacturers see aluminum as a material with a profitable weight reduction potential, but very few have considered magnesium.

Table 9. Overview of Passenger Seat Manufacturers for the Ground Public Transit Industry

Company	Main Markets in the Transportation Industry
Canada	
Multina 1275 Janelle St. Drummondville, QC J2C 3E4 Tel.: (819) 478-8145 Fax: (819) 477-1071 www.multina.com	• Motor coaches • Urban trains • Trains
Testori Americas PO Box 40 Summerside, PEI C1N 4P6 Tel.: (902) 888-3200 Fax: (902) 436-4456 www.testori.pe.ca	Turnkey interiors for: • Trains • Planes
United States	
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Comments

- Amaya-Astron Seating, based in Mexico City, exports its bus and motor coach seats to the American, Canadian and South American markets. The company has a technology transfer agreement with the Spanish firm Fainsa, a major manufacturer of seats for the European market, and a marketing agreement with Freedman Seating in the United States.
- Esteban is a Spanish corporation with plants in Spain, the United Kingdom, Brazil and Mexico. Estaban products are distributed mainly in the United States and Canada by Windsor Seating (Peachtree City, GA).
- Other players, such as C.E. White Company in Ohio, specialize more in seats for small buses.

2.4 CURRENT APPLICATIONS FOR MAGNESIUM SEATS

Magnesium began to be used in seat frames in about 1997 when several automobile industry applications of magnesium appeared on the market. The following is a brief overview of various new applications launched in recent years.

Automobiles

In the automobile industry, magnesium is currently used in seat frames, instrument panel beams, steering wheel frames and various support components. The process used to make magnesium parts (without exception) is pressure die casting.

- GM introduced rear seat frames consisting of a single piece of magnesium in the 1997 models of its U-body minivan platforms (Lumina APV and Pontiac Transport models). Later GM introduced magnesium seat frames in the 1999 models of its Chevrolet Venture and Oldsmobile Silhouette minivans. Equipment manufacturer Delphi also introduced magnesium cushion frames for the seats of the GM EV1 (electric vehicle) launched by the Saturn Division in 1997. These frames are now used in Cavalier and Sunfire models.
- In 1997, the Manufacturing Science and Technology Group of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia announced the development of one of the world's lightest magnesium automobile seat frames through a partnership with Henderson's Automotive Group. The seatback was made of a single piece of magnesium, which replaced an assembly of 13 steel parts and resulted in a weight reduction of over 50%. The seat had twice the load capacity and a price equivalent to a traditionally designed seat.

- For its 156 model, introduced in 1997, Alpha Romeo used a two-part magnesium frame for its front seats and obtained a weight reduction of 4 kg per seat.
- In 1998, Mercedes installed a magnesium seat frame in its SL Roadster models that was strong enough to incorporate the upper anchoring device of the seatbelt. The seat consisted of five magnesium parts that weighed a total of 8.5 kg and were made from AM50 and AM20 alloys. In 1999, Mercedes used magnesium for its S Series seats.
- In 1999, Araco, a corporation affiliated with the Toyota Group in Nagoya, Japan, announced the start of production of magnesium seat frames using the Thixomolding process.
- More recently, Renault installed magnesium seat frames in its Espace 2003 minivans.
- Finnveden (Sweden) announced in December 2003 that it had landed a five-year contract with seat manufacturer Grupo Antolin (Spain) to build magnesium seat armrests using a pressure die casting process.
- The bucket seat frames of the Ford Motor Company's Mustang Cobra are made of magnesium, and the brand new Jaguar XJ 2004 uses cast magnesium parts for its seat frames.

Heavy trucks

- Driver seat manufacturer Sears Seating (United States) uses a magnesium frame that provides orthopedic support for its air suspension Atlas seats for Class 7 and 8 heavy trucks.

Trains

- Seat manufacturer Compin (Belgium) has been investing in the development of magnesium solutions for its long-distance train seats since 1991. The company uses magnesium mainly for its high-speed train (HST) seats, including magnesium seat frames and armrests for the Korean HST and magnesium seat shells, armrests and seat trays for the Duplex HST in France. In the latter case, the use of magnesium, compared with aluminum, resulted in a weight reduction from 26 kg to 14 kg. This switch to magnesium was made at the request of clients and major manufacturers in order to reduce vehicle mass (particularly in the case of two-level vehicles).

3. TECHNOLOGICAL AND ECONOMIC ISSUES RELATIVE TO MAGNESIUM SEATS

This section looks at the major technological and economic issues that may influence choices of new materials made by the principal stakeholders involved in manufacturing urban and intercity bus seats.

3.1 NORTH AMERICAN SEAT DESIGN STANDARDS

We found that there are no specific North American standards for motor coach passenger seat design.

A recent study of occupant protection in buses [6] conducted for Transport Canada provides a profile of various Canadian and international standards for passenger protection and analyses the causes of serious accidents involving motor coaches. This study, conducted by Rona Kinetics & Associates (RKA), reveals the following about the design and validation of new passenger seats for motor coaches:

- Australian standards, followed by European standards, are the strictest in the industry;
- Except for school buses, for which there is a specific passenger seat standard (CMVSS/FMVSS 222), other current Canadian and American standards mainly concern driver seats or seats equipped with seatbelts.

This study is a good starting point for passenger seat design standards because it includes the following:

- Statistics for motor coach accidents involving serious injury and/or death in North America, Europe, Australia and the United Kingdom;
- Main design standards for motor coaches in North America, Europe, Australia and the United Kingdom;
- Various options selected by these countries to increase passenger protection.

In the following, reference is made to the main industry standards listed in this study and to other standards used by the motor coach and passenger seat manufacturers that were interviewed. The specific objective is to have a clear understanding of the main differences between the safety standards for motor coach passenger seats and those for passenger trains in order to compare them with standards used by the automobile industry where large numbers of magnesium seats have already been marketed for a few years.

3.1.1 Canadian and American standards

All motor coaches built in Canada or imported must meet Canada Motor Vehicle Safety Standards (CMVSS) and the Federal Motor Vehicle Safety Standards (FMVSS) of the United States. For the motor coach components concerned in the following, the Canadian and American standards are exactly the same.

There are 18 standards for occupant and driver protection in the event of collision. Only five of these standards deal directly with seats: Standards 207, 208, 209, 210 and 222 (see Table 10). When looked at more closely, four of these standards are only valid for driver seats and/or seats for which seatbelts are mandatory, whereas Standard 222 covers passenger protection on school buses. Because the current Canadian and American regulations do not make the wearing of seatbelts mandatory for occupants of motor coach passenger seats, Standards 209 and 210 do not apply for the time being.

Table 10. Canadian/American Design Standards (CMVSS/FMVSS)

CMVSS/FMVSS Standard	Description	Driver Seat	Passenger Seat
207	Anchorage of Seats	Yes	No
208	Occupant Restraint Systems in Frontal Impact	Yes	No
209	Seatbelt Assemblies	Yes	N/A
210	Seatbelt Anchorages	Yes	N/A
222	School Bus Passenger Seating and Crash Protection	No	Yes

Although the mandatory wearing of seatbelts in motor coaches is a topic that makes the headlines when a serious-injury or fatal accident occurs, it should be pointed out that Transport Canada and industry experts do not foresee any amendments to North American legislation to make seatbelts mandatory within 10 or more years.

Transport Canada set up a commission to hold nation-wide consultations on the matter in Canada's major cities between June 1999 and June 2000 [7]. Supervised by Price Waterhouse Coopers, this commission held meetings with industry representatives to discuss the main concerns about motor coach safety and the possibility of installing seatbelts.

The commission's conclusions shed light instead on the problem of public perception. According to motor coach transportation industry statistics, motor coaches are one of the safest modes of transportation. In addition, the Commission revealed other passenger safety aspects that should be given greater priority. It pointed out that drivers should be given better training, that the various standards from one province and territory to the next should be harmonized, and that fleet operators should carry out periodic inspections.

Nonetheless, motor coach and passenger seat manufacturers are already studying the restrictions imposed by a mandatory seatbelt law and the cost of installing seatbelts.

American Public Transportation Association Standards (United States)

It was confirmed in the discussions with American seat manufacturers that some manufacturers use APTA standards (*Standard Bus Procurement Guidelines*) as a reference. Although these standards are mainly for designers of urban bus passenger seats, they can also be used as a reference for manufacturing motor coach seats.

These standards mainly cover the following:

- Dimensions of seats and spaces between seats;
- Seat positioning and orientation in various types of buses;
- Design standards to be followed and seat durability;
- Finishes and materials used.

Table 11. Overview of APTA Standards (United States)

Load Case	Experimental Conditions	Area of Application	Maximum Deformation (mm)
Deceleration	10 G Duration: 10 ms	Entire seat	< 355 (upper part of seat) < 51 (seat cushion when a male occupant of 95th percentile height hits against the seatback)
Vertical force	2.23 kN	Cushion	6.5
Horizontal force	2.23 kN	Seatback (force equally distributed over the seatback)	6.5
Horizontal force	2 20-kg bags Cycles: 80,000 (equally distributed toward the front and rear)	Seatback onto the back and front of which is projected a 20-kg bag of sand attached to 900-mm rope at a distance of 150, 200, 250 and 300 mm	
Vertical force	1 20-kg bag Cycles: 4,000	Seat cushion onto which is projected a bag of sand from a distance of 150, 200, 250 and 300 mm	
Vertical force	0.67 kN Cycles: 100,000	A 70-kg weight in the shape of human buttocks is thrown from a height of 90 mm	

Table 11 shows the principal load cases described in the section on passenger seat design and durability. APTA experts developed these load cases in accordance with a bus's estimated maximum deceleration of 10 G during a collision—a value similar to European standards, but considerably less than the Australian standard based on an assumed deceleration greater than 20 G.

A closer look at this standard shows that load cases based on normal seat use are also included to help manufacturers minimize premature wear and tear on various materials used in seat assembly.

Since there is no single North American standard that all motor coach seat manufacturers use as a reference, it is helpful to study and compare other existing standards in Europe and Australia.

3.1.2 European standards

The Economic Commission for Europe (ECE) is the organization responsible for enacting legislation relative to seats for large-size passenger transit vehicles in Europe and for approving such seats. As shown in Table 12, there are currently three standards that apply to passenger seat design.

Table 12. European Design Standards (ECE)

ECE Standard	Description	Revision and/or Amendment
ECE Regulation 14	Uniform Provisions Concerning the Approval of Vehicles with Regard to Safety-Belt Anchorages	2003
ECE Regulation 16	Uniform Provisions Concerning the Approval of: I. Safety-Belts and Restraint Systems for Occupants of Power-Driven Vehicles II. Vehicles Equipped with Safety-Belts	2003
ECE Regulation 80	Uniform Provisions Concerning the Approval of Seats of Large Passenger Vehicles and of These Vehicles with Regard to the Strength of the Seats and Their Anchorages	2001

Since ECE Regulations 14 and 16 apply to seats equipped with seatbelts, the standard of special interest in terms of load case is ECE Regulation 80, described in Table 13.

Although this standard is not yet mandatory in Europe, motor coach and passenger seat manufacturers take it into consideration. In North America, it was found in discussions with some seat manufacturers and some bus manufacturers who fabricate their own seats that this European standard is often used as a reference.

Table 13. Overview of ECE Regulation 80

Load Case	Experimental Conditions	Area of Application	Maximum Deformation(1) (mm)
Deceleration	10 G Duration: 10 ms	Entire seat	400
Horizontal force	1.0 kN Duration: 200 ms	Seatback (force equally distributed over the width of the seatback up to a predetermined height of between 70 cm and 80 cm from the floor)	
Horizontal force	2.0 kN Duration: 200 ms	Seatback (force equally distributed over the width of the seatback up to a predetermined height of between 45 cm and 55 cm from the floor)	
Vertical force	5.0 kN(2)	Anchorage	

1: This document also refers to maximum deformation values at force application points that must be at least equal to 100 mm for 1 kN of force and 50 mm for 2 kN of force in order to provide the seatback with some flexibility and shock absorption for passengers projected forward.

2: This force is multiplied by the number of seats supported by the anchoring structure (usually two).

It is worth noting that the European Union stipulates that seatbelts must be installed on all seats that do not have passenger seats ahead of them. The installation of seatbelts with two attachment points is also mandatory on all motor coaches weighing more than five tonnes. In the case of motor coaches weighing between 3.5 and 5 tonnes, manufacturers can choose between seatbelts with two or three attachment points.

Since October 1, 2001, it has been a requirement in some countries, such as the United Kingdom, that seatbelts with two or three attachment points be installed on motor coaches weighing more than 3.5 tonnes. As RKA mentions in its report [6], not all European countries comply with the directive recommending the installation and use of seatbelts in motor coaches. The European Commission is currently studying the situation in order to make this directive, issued in the early 1990s, mandatory across Europe.

3.1.3 Australian standards

Australian standards (Australian Design Rules or ADR) are the strictest standards in the industry. In fact, unlike European and North American standards, seatbelts with three attachment points have been mandatory since the early 1990s.

There are four design standards outlining specifications with which seat manufacturers must comply (see Table 14); however, they are mainly intended for smaller buses that carry fewer passengers than motor coaches. Motor coach seat manufacturers must comply with ADR 68. Table 15 shows the main load cases applied for this standard, i.e., cushion, seatback, entire seat and seat anchorages.

Table 14. Australian Design Rules (ADR)

ADR Standard	Description	Type of Vehicle and/or Applicability
3	**Seats and Seat Anchorages**: Specifies requirements for passenger seats, their attachment assemblies and their installation.	All seats on buses weighing 3.5 tonnes or less
4	**Seatbelts**: Specifies requirements for passenger and driver restraint systems in order to avoid ejection and minimize serious injuries during a collision.	All bus seats
5	**Anchorages for Seatbelts and Child Restraint Systems**: Specifies requirements for anchorages for both seatbelt assemblies and child restraint systems to ensure passenger safety and comfort.	Bus driver seats already comply with the ADR 68 standard
66	**Seat Strength, Anchorage Strength and Padding**: Specifies requirements for the strength of seats, anchorages, seatbelts and padding of seats and accessories to ensure passenger protection.	All bus seats. Does not apply if the seat complies with the ADR 68 standard
68	**Occupant Protection**: Specifies requirements for the strength of seats, anchorages, seatbelts and padding of seats and accessories to ensure passenger protection.	Seats on all buses weighing up to 5 tonnes and buses exceeding 5 tonnes after July 1, 1994

Table 15. Overview of the ADR 68 Standard

Load Case	Experimental Conditions	Area of Application	Maximum Deformation (mm)
Deceleration	20 G Duration: 10 ms	Entire seat	
Moment load	530 N·m	Upper part of seatback	
Vertical force	8.9 kN	Seat anchorage simulating an acceleration of 20 G	
Horizontal force	17.7 kN		
Horizontal force	1.0 kN Duration: 200 ms	Seatback (force directed forward and evenly distributed over the width of the seat at a height of 70-80 cm from the floor)	150
	2.0 kN Duration: 200 ms	Seatback (force evenly distributed over the width of the seat at a height of 45-55 cm from the floor)	150

3.1.4 Comparison of principal current standards

Table 16 provides a summary of the three standards described in Tables 11, 13 and 15. In comparing these standards, the main differences to be noted are dynamic loads and the amounts of force applied to anchorages. The Australian standard is clearly the strictest, while the European standard is stricter than the American standard.

Table 16. Comparison of International Standards for Motor Coach Passenger Seats

Load Type		Load Case Description	Standard		
			APTA (USA)	**ECE 80 (Europe)**	**ADR 68 (Australia)**
	Seat	Horizontal force (applied simultaneously)			
		– H1 position on the seatback		1.0 kN @ 70-80 cm	1.0 kN @ 70-80 cm
		– H2 position on the seatback		2.0 kN @ 45-55 cm	2.0 kN @ 45-55 cm
		– Evenly distributed over the seatback	2.23 kN		
		Vertical force - Cushion	2.23 kN	(See force applied to anchorage)	
		Moment load applied to the upper part of the seatback	N/A	N/A	530 N·m
	Anchorage	Force applied to anchorage (double seat)	2.25 kN x 2 = 4.5 kN	10 kN	[8.9 kN (cushion) + 17.7 kN (seatback)] x 2 = 53.2 kN
Dynamic	Seat and anchorage	Average deceleration ($G = 9.81\ m/s^2$)	10 G	6.5-8.5 G	20 G
		Minimum speed of vehicle during impact simulation	N/A	30-32 km/h	49 km/h
		Speed of pendulum simulating shock to the head	N/A	N/A	6.69 m/s
		Acceptability Criteria			
		- head	< 400	< 500	< 1,000
		- thorax	N/A	< 30 G	< 590 m/s^2 (60 G)
		- femur	4.45 kN	< 10 kN and the value of 8 kN must not be exceeded for more than 3 ms	< 10 kN

NB: To obtain the vertical force on the cushion set out in the APTA standard, multiply this amount of force by two in order to compare it with the force applied to the anchorage specified in the European standard. Also multiply by two the amounts of force specified in the Australian standard, which are usually called *body blocks*, which actually represent two shapes positioned on the seat to simulate the weight of a person weighing about 135 kg and undergoing deceleration of 20 G.

Note that the Australian standard is the only standard requiring that a moment load be applied to the upper part of the seatback. This load case is similar to that required for automobile seats in the United States FMVSS and Canada's CMVSS. In addition, the deceleration required in the Australian standard during the calculation phase and validation tests is at least twice that required in the APTA and European standards.

Lastly, the RKA study [6] points out that there are several initiatives to harmonize the European standards with the North American standards. An international committee set up in 1998 has been working to harmonize various vehicle safety standards. In parallel with these initiatives, other countries such as Australia are harmonizing their standards with those of Europe (a project completed in 2003 by the Department of Transport and Regional Services, which is about to publish some recommendations for harmonizing its standards while ensuring that passenger protection is in no way reduced in the process).

3.1.5 Standards for passenger train seats

In examining various seats offered by major North American and European manufacturers, it was found that most of these firms provide seats suited to the requirements of both motor coach and railway industry operators.

It was confirmed in the discussions with the seat manufacturers serving these two industries that a lighter seat made of magnesium could be developed for possible use in these two industries. However, given the railway industry's conservative approach to adopting a new material, it was pointed out that experiments should be conducted in the motor coach industry first. Once these initial experiments were conclusive, the railway industry could then be considered.

In these circumstances, it was therefore relevant to study the standard for passenger train seats and to position it in relation to other current standards for motor coaches.

Table 17. APTA SS-C&S 016-99 Standard for Seating in Commuter Rail Cars (United States)

Load Case	**Experimental Conditions**	**Area of Application**
Deceleration	8 G Duration: 250 ms	Entire seat
Horizontal force	1.35 kN Duration: 5 s	Upper part of the seatback and evenly distributed over its width
Vertical force	2.0 kN Duration: 5 s	Cushion at the centre of the front part of the seat that supports the thighs
Lateral force	Deceleration: 4 G Duration: 200 ms	Application to the seat's centre of gravity of a horizontal force equal to 4 times the weight of the seat and its components
Vertical force	Deceleration: 4 G	Application to the seat's centre of gravity of a vertical force equal to 4 times the weight of the seat and its components

Table 17 shows that the static and dynamic load cases for commuter rail cars are either equal to or less than those for motor coach seats (according to the APTA Passenger Rail Equipment Safety Standards).

3.2 TESTS AND VALIDATIONS

3.2.1 Tests used to approve materials

It was confirmed in the consultations with North American motor coach manufacturers that every new material must meet the CMVSS/FMVSS 302 flammability standard, which is the same standard used in the automobile industry to certify new materials.

Since it was known that a magnesium seat developed for the motor coach industry could be marketed for use in the railway industry, additional tests required by the railway industry were identified and carried out by a certified organization.

In addition to the CMVSS/FMVSS 302 standard required by the automobile and motor coach industries, APTA requires three additional tests for passenger trains and Bombardier Transportation requires a fourth test in order to certify any new material. Table 18 provides descriptions of these various tests and the results obtained.

Table 18. North American Tests Required for the Certification of New Materials

Standard	Description	Tested Alloy	Laboratory	Thickness	Result
CMVSS and FMVSS 302	Measurement of the rate of combustion of a material when exposed to a flame for 15 seconds	AM60B	Noranda (2002)	2 mm and 3.8 mm	No combustion
ASTM E 162 (NFPA 258)	Flammability of materials with a radiant heat source	AZ31	Bodycote	2.3 mm	No combustion
ASTM E 662	Density of smoke (with or without flame)	AM60B	Bodycote	4.3 mm	Meets the Federal Railroad Administration standard
ASTM E 1354 (ISO 5660)	Heat and visible smoke release rates for materials and products using an oxygen consumption cone calorimeter	AM60B	Bodycote	4.1 mm	No combustion
Bombardier SMP-800-C	Analysis of CO, HF, HCN, HBr, SO and NO in combustion gases	AM60B	Bodycote	4.3 mm	Meets the Bombardier standard

In 2002, Noranda conducted magnesium flammability tests in its own laboratory and concluded that this alloy met the CMVSS/FMVSS 302 Standard. Although the Noranda laboratory was not certified by the Canadian Engineering Accreditation Board (CEAB) when this test was carried out, we did not consider it relevant to conduct it over again, because the fact that magnesium is currently used in the automobile industry demonstrates beyond any doubt that this material already meets this standard. However, seat manufacturers will have to have the selected magnesium alloys qualified again by a certified organization to ensure that they comply with the FMVSS 302 standard. *It is also strongly recommended that these certification tests be carried out on* *finishes, i.e., primers and paints used to coat magnesium that may be applied to the seat to protect it against corrosion or vandalism, or applied simply for esthetic reasons.*

Since it was not possible to obtain enough of the AM60B alloy for the ASTM E 162 test, the AZ31 alloy was used for this test. However, although a new seat would very likely be made from the AM60B alloy, an expert from Norsk Hydro, one of the main magnesium producers, confirmed that the results would not be influenced by the slight difference (3% of aluminum) in the composition of these two alloys.

The results of the tests carried out by independent firm Bodycote in Ontario showed that the AM60 and AZ31 magnesium alloys meet the standards of the motor coach and train industry in terms of flammability of materials and their possible toxic smoke emissions while exposed to intense heat. Reports of the four tests conducted by Bodycote are included in Appendix B.

3.2.2 Tests usually carried out by seat manufacturers

When various standards were studied, it was found that there were two principal load cases to consider in passenger seat design: static and dynamic load cases.

As with the designing of parts for the automobile industry, static load cases are usually used to pre-dimension seats in the initial design stages, while dynamic load cases are used to obtain optimum seat design in the advanced design stages.

The two main load cases are analysed from the beginning using the calculation-per-finished-component method for developing new products, which is used almost everywhere. Once completed, these initial analyses help engineers identify the worst load case that will have a serious impact on the final dimensions of the part to be designed. Once this worst case or these worst cases are known, the engineers will continue optimizing the seat dimensions while ensuring that the revised design meets the requirements of all other load cases.

When conducting tests on new seats for public transit, seat manufacturers usually make significant use of the European ECE 80 standard as their model, as follows:

- Force applied to seatbacks, base structures, cushions, seatbelt attachment points, armrests, seat trays and footrests;
- Fatigue and service life tests on movable components, such as headrests, seatbacks, armrests and footrests;
- Tests simulating the crushing of various types of cushions by users (see APTA standard, Table 11).

There are two main challenges in a motor coach seat design project. Optimum design must be correctly obtained for the following:

- Seatback geometry to ensure that the seatback correctly absorbs the impact of a rear passenger projected forward while protecting the passenger occupying the seat;
- Double seat anchoring to ensure that the double seat does not tear apart and does not result in or cause serious injury to passengers.

Laboratory tests for a new magnesium seat must make it possible to (1) validate the structural analyses carried out digitally on the seat design and (2) ensure that the selected shaping technology can meet the criteria for harmonizing standards required by users.

Another important point to highlight is that, regardless of the material selected for building a new lighter seat, no structural part of the seat can have sharp or jagged ends that might cause physical injury to passengers. In that regard, and particularly for seat anchoring parts, it would be worthwhile to study not only cast parts, but also extruded parts that usually have superior mechanical properties.

Corrosion test

According to the APTA standard entitled Standard Bus Procurement Guidelines, it is important that all new materials used in buses be corrosion-resistant, either through their intrinsic properties or with the help of a surface coating. The materials must pass a salt spray exposure test for 336 hours, in accordance with the ASTM B-117 standard, without sustaining any damage that might compromise the structural integrity of the materials and without losing more than 1% of their weight.

Since seats are located inside vehicles, they are not exposed to the weather. However, the part of the seat in direct contact with the floor (anchoring structure) can be exposed to snow, water, salt and cleaning products. The seat design shown in Section 4.4.3 uses an extruded aluminum part, which is already currently used in several European seat designs and possesses better mechanical properties, to anchor the seat to the floor.

Cushion and seatback frames can be designed to repel liquids (soft drinks, coffee, water, etc.) accidentally spilled on seats, thus preventing any galvanic corrosion in the presence of other materials. Since magnesium can corrode very quickly if placed in a galvanic environment, it must always be insulated with neutral materials (such as polymers) to prevent it from becoming a sacrificial electrode when placed in direct contact with aluminum, cast iron or steel in an aqueous environment.

It should be mentioned that magnesium seat frames used in automobiles do not undergo anti-corrosion surface treatment because they do not come in direct contact with corrosive elements.

3.2.3 Comparison with automobile industry tests

A comparison was made between the specifications for current applications in the automobile industry and the specifications of the European ECE 80 standard, which is widely used in the development of new motor coach seats.

Several interesting technical aspects arose when the automobile industry standards for the design of magnesium seats and instrument panels were studied more closely.

Magnesium car seats

Car seats must comply with the CMVSS/FMVSS 207 standard and be able to withstand the following:

- Deceleration of 20 G in both directions (horizontal and vertical);
- Moment load of 373 Nm applied to the upper part of the seatback;
- Combined force of deceleration and force exerted by the seatbelt if the seatbelt is fastened to the seat (as is the case with most seats currently on the market);
- Stress exerted on the seat during a side impact collision;
- Submarining risks;
- Moment loads caused by rear-end collisions.

When these forces are compared with those of the ECE 80 standard or even the ADR 68 standard, it becomes clear that the specifications for a new magnesium passenger seat for motor coaches are less strict than those for automobile seats.

The main reason for the stricter requirements imposed on automobile seats is that cars decelerate faster in a collision than do motor coaches because of the substantial inertia difference. Faster vehicle deceleration inevitably increases the amount of force transmitted to various vehicle components, including seats.

Based on this comparison, it can be said that *magnesium passenger seats can be designed for motor coaches because those that have already been manufactured for the automobile industry were subjected, during the approval process, to load cases equal to and/or exceeding the strictest standard in the motor coach industry.*

An article submitted to the annual Society of Automotive Engineers (SAE) convention in 1994 [8] describes the positive conclusions of the finite element analysis during the development of a new magnesium seatback and during tests carried out on prototypes in accordance with FMVSS 208 and 210 standards.

Automobile instrument panels

Instrument panel frames play a critical role in collisions and help minimize the risk of injury if vehicle occupants (whether wearing seatbelts or not) are projected forward during impact.

A magnesium intrument panel must meet the following standards:

- CMVSS and FMVSS 201 – Occupant protection in interior impact (ECE 21 and ADR 21);
- CMVSS and FMVSS 204 – Steering control rearward displacement;
- CMVSS and FMVSS 208 – Occupant crash protection;
- CMVSS and FMVSS 214 – Side impact protection.

Because the instrument panel is attached directly to the front columns of the vehicle and because it prevents the engine from entering the passenger compartment and provides support for critical components, such as the steering wheel column, air conditioning system and air bags, it is probably the component that best illustrates the many potential uses of magnesium alloys.

To successfully pass numerous validation tests, this component must have the following characteristics:

- Ability to withstand considerable stress during collisions;
- Ability to absorb and dissipate energy when being bent out of shape;
- Good mechanical properties such as creep resistance;
- Superior mechanical properties (elongation at fracture, yield strength and ultimate tensile strength);
- Considerable rigidity to ensure a resonance frequency above 35 Hz;
- Ability to provide high dimensional accuracy in order to simplify the assembly of various components.

Based on the various tests carried out on magnesium instrument panels by the automobile industry, particularly those related to energy absorption when an occupant not wearing a seatbelt is projected directly onto the instrument panel frame, *there should be no major problems in designing a new magnesium passenger seat for motor coaches that is able to withstand and absorb the energy of a rear passenger projected forward against the seatback in front.*

3.3 PROPERTIES OF MAGNESIUM ALLOYS

This section compares the various mechanical properties of magnesium and its alloys with those of other materials. Various current applications of magnesium in the automobile industry are also outlined to demonstrate the considerable potential for using magnesium in the transportation industry.

3.3.1 Introduction to magnesium

Magnesium is the lightest of all structural elements and the eighth most abundant element in the earth's crust (2.7%). Magnesium does not exist in nature in its metallic form. It has to be extracted from certain ores, such as magnesite, serpentine and dolomite, or from seawater, where it is found in abundance.

The metallic magnesium produced through ore or seawater extraction is usually called primary magnesium and is used for non-structural applications, such as the following:

- An alloying element in aluminum alloys (40%–45% of consumption);
- Steel desulfurization (about 10% of consumption);
- Various chemical and electrochemical applications (10% of consumption).

In terms of structural applications (35%–40% of total consumption), magnesium is mainly used in the pressure die casting of parts for the automobile industry and in the casting (permanent mould casting and Thixomolding) of bodies and cases for electronic products (cameras, computers, portable telephones, etc.). Magnesium is also used for some military and aerospace applications involving gravity casting technologies, i.e., processes such as sand casting, permanent mould casting, plaster mould casting, lost-wax process and low-pressure mould casting.

Gravity casting technologies are currently used to develop new applications involving a range of production volumes, regardless of the area of application.

For example, when new parts are developed for the automobile industry, it is regular practice to initially produce parts using the sand casting process before developing the equipment for producing them with pressure die casting technology.

Just as magnesium is used as an alloying element with other metals, small quantities of other elements are often added to pure magnesium to create magnesium alloys with enhanced properties. The elements most often used are aluminum, zinc, manganese, silicon, iron, copper and rare earths.

The alloys most often used in the automobile industry are AM50, AM60 and AZ91D alloys used for cast parts, while the AZ31 alloy is the most common alloy for fabricated products (extruded and laminated).

The letters and numbers used in the names of magnesium alloys indicate the main elements added to the pure magnesium, followed by the percentages of these additives in the alloy's composition. For example, in the case of alloy AM60, the first letter and the first number indicate that aluminum was added to the magnesium at a percentage of 5.5% to 6.5% of the total weight. The second letter and second number indicate that the percentage of manganese added was 0.26% to 0.50% of the total weight.

The development of alloys with specific properties is a key element in the development of new applications. The elimination of iron and nickel from magnesium alloys in the early 1980s improved their resistance to corrosion and made it possible to develop many new applications for the automobile industry.

When the various alloys associated with metal forming technologies are studied, it quickly becomes apparent that there is a limited number of magnesium alloys, compared with available aluminum alloys. However, progress is being made and new alloys are being developed in order to expand the areas of application for magnesium.

In recent years, several major magnesium producers have developed new high-temperature, creep-resistant alloys that can be easily used in pressure die casting. Noranda developed the AJ62 alloy, which BMW is about to use in the casting of a new engine block [9]. Research carried out by Noranda [10] demonstrated that the AJ62L alloy has a greater energy-absorption capacity than the AM60B alloy.

Another producer, Dead Sea Magnesium, recently developed the MRI 153 alloy. Volkswagen, a shareholder in Dead Sea Magnesium, has conducted numerous studies and bench tests since this new alloy was marketed. Industry experts predict that new applications using this alloy will soon be developed for Volkswagen and Volkswagen's Audi Division cars.

3.3.2 Mechanical properties of magnesium alloys

Several properties, including the following, make magnesium a material of choice nowadays for various processes and applications (see 1993 article published for the SAE [12]).

- Lightest of structural metals;
- Rigidity (best rigidity/density ratio);
- High degree of castability (better fluidity in liquid state than aluminum);
- Vibration-absorption capacity (reduces vibrations transmitted to passengers and has potential to improve comfort in some cases);
- Electromagnetic protection capacity;
- Thermal conductivity;
- Can be easily machined;
- Can be recycled at low cost;
- Dent and impact resistant.

Table 19 shows the properties of the AM60 alloy, compared with the A380 aluminum alloy, Zamak3 zinc alloy and 1020 steel.

Table 19. Mechanical Properties of Magnesium Alloys and Other Materials

Property	Unit	AM60B (Mg)	AJ62L (Mg)	A380 (Al)	Zamak3 (Zn)	1020 Steel (*cold rolled*)
Young's Modulus						
- stress	GPa	45.0	44.7	71.0	85.5	205.0
- shear and torsion	GPa	17.0	N/A	26.5		80.0
Poisson ratio		0.35	0.28	0.37	0.39	0.29
Density	g/cm^3	1.79	1.8 [a]	2.68	6.6	7.87
Yield strength	MPa	130	144	160	221	350
Ultimate tensile strength	MPa	220	254	320	283	420
Compressive yield strength	MPa	130	109	N/A	414	
Elongation at fracture	%	6-8	9	3.5	10	10%–15 %
Maximum fatigue limit (See: R.R. Moore 5 x 10^8 cycles)	MPa	70	N/A[b]	138	47.6[d]	N/A
Thermal expansion coefficient (between 20°C and 100°C)	µm/m·K	26.0	27.31[c]	21.8	27.4	11.7
Specific damping capacity (at 100 MPa)	%	53		4		N/A
Impact energy - Charpy test, 10 x 10 mm samples without notches - Smooth test piece	J	6-18	9.6		58.3	N/A

a: AJ52x value measured by Intermet Corp die casting firm [13]

b: Tests in progress (until late 2004). Calculated AJ62x value: 80 MPa, axial fatigue R = -1 for 10 million cycles [9]

c: AJ52x value from Noranda database

d: Fatigue test according to DIN 50113 standard

The most distinctive property of magnesium is its lightness. It is 33% lighter than aluminum and four times lighter than steel. Another important distinctive property is its rigidity/density ratio, which ranks it first among materials used for structural applications. A third equally important property is magnesium's ability to absorb vibration energy.

The ratio of Young's moduli for the AM60 alloy, compared with the A380 alloy, is almost equal to the density ratio. Similarly, the yield strength and ultimate tensile strength of the AM60 alloy are 19% and 31% lower, respectively, than those of the A380 aluminum alloy. Magnesium alloys allow elongations at fracture nearly two to three times greater than those of the A380 alloy.

In a crash where a rear seat passenger is projected forward against the back of the seat in front, the high degree of elongation at fracture of magnesium alloys allows for greater energy absorption and provides a more gradual cushioning for the movement of the passenger projected forward. This property of magnesium alloys is one of the main reasons North American builders use them for automobile steering wheel frames and for the bottom cross piece used to protect the front passenger's legs in a crash.

The AM60B alloy is currently one of the most regularly used magnesium alloys. For example, it is used to manufacture steering wheel frames, car seats and instrument panels. Along with other AM series alloys (AM60B, AM50A and AM20), it is used to manufacture radiator supports and many other applications requiring good elongation at fracture, excellent corrosion resistance, and sufficient hardness and impact resistance to withstand reasonable amounts of force.

In the assessment of passenger seat production costs in the Chapter 4, the AM60B alloy is one of the alloys suggested for pressure die casting. However, Noranda's new AJ62L alloy has properties that are just as good or even better than those of the AM60B alloy in terms of elongation at fracture and yield strength. These two alloys should therefore be assessed more closely for the purposes of a seat design project.

To make good use of magnesium's mechanical properties, which are slightly inferior to those of aluminum, maximum use should be made of the combined effects of the following when designing new parts:

- increased inertia of various sections of a part;
- use of thin-walled ribs;
- use of thinner walls, usually between 2 mm and 4 mm;
- consolidation of several parts into one;
- potential for casting more complex shapes, taking advantage of magnesium's excellent fluidity.

Designers and engineers must have an excellent knowledge of magnesium alloys, metal forming processes and digital simulation tools in order to correctly optimize the new part according to precise specifications.

Through an ingenious combination of its properties, magnesium has succeeded in replacing steel for structural applications where steel used to be king, even though Young's modulus for magnesium is almost five times less that of steel. However, some weaknesses should also be taken into account. For example, magnesium has limited creep strength, making it necessary in many cases to increase the number of attachment points for gear boxes. It also has limited corrosion resistance, which means that magnesium parts must be isolated from steel parts to prevent galvanic corrosion.

3.3.3 Transportation industry applications

Magnesium has been used in the transportation industry for a long time. Since the early 1990s, Germany has been using it for military applications. Some German and American airplanes in the Second World War were built mostly from cast, extruded and sheet magnesium parts (e.g., Arado 196, US XP-56 and F-80 aircraft).

In the early 1940s, Volkswagen made significant use of magnesium to manufacture many parts for its famous Beetle (air-cooled engine blocks, gearboxes, etc.). But after the Second World War and up to the early 1980s, magnesium was sidelined somewhat, particularly because the first alloys were very sensitive and because production was very limited. The production of very pure magnesium alloys finally made it possible to achieve corrosion resistance levels comparable to those of aluminum alloys. Meanwhile, improvements were made to the presses used for pressure die casting (cycle time, cylinder speed, hydraulic system, etc.). As a result, these alloys paved the way for developing many new structural applications for magnesium in the automobile industry.

The major breakthrough for magnesium applications began in the 1980s and was followed by more developments throughout the 1990s when automobile manufacturers came under pressure from American environmental standards (Corporate Average Fuel Economy [CAFE]) to reduce vehicle weight or at least mitigate increases in vehicle weight.

In the early 1980s, manufacturers began to use magnesium to build part of the steering column casing and steering wheel frame. The application for the steering wheel frame proved very successful and greatly helped raise awareness of magnesium around the world. Today about 85% of steering wheel frames are manufactured from magnesium alloys.

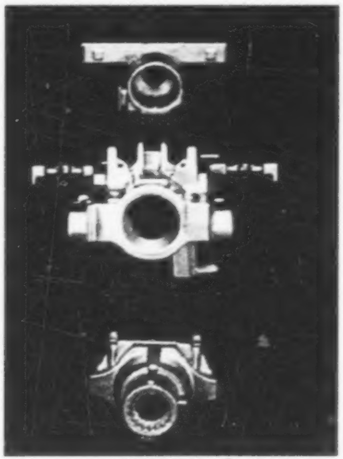

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Figure 10. Magnesium Steering Column Components (Daimler Chrysler)
Weight of three parts: 1.1 kg

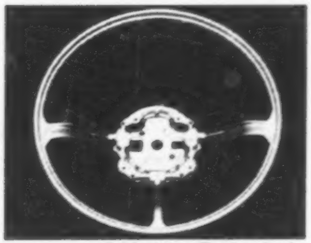

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Figure 11. Magnesium Steering Wheel Frame (Alfa Romeo)
Weight: 0.7 kg

Apart from magnesium's use in steering wheel frames, the application generating the strongest growth in magnesium use in the automobile industry is undoubtedly magnesium instrument panels. Magnesium frames are providing stiff competition for steel frames.

In the early 1990s, the steel cross-beams used to support steering columns and all other dashboard accessories were replaced by a single cast magnesium part. Typically, the pressure die casting of these magnesium cross-beams made it possible to replace up to 70 folded and welded sheet steel parts used to manufacture the cross beam. In addition to a substantial weight reduction, this consolidation of parts helped simplify assembly (thus lowering manufacturing costs) and reduce vibration (fewer parts joined together), which vehicle owners often found unpleasant. Nowadays, these magnesium parts are found in many luxury and commercial vehicles (see examples in Figures 12 and 13).

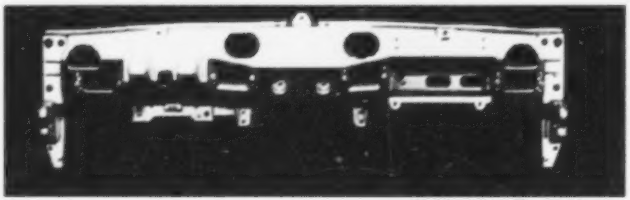

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Figure 12. Magnesium Instrument Panel for the BMW Mini
Weight: 3.6 kg

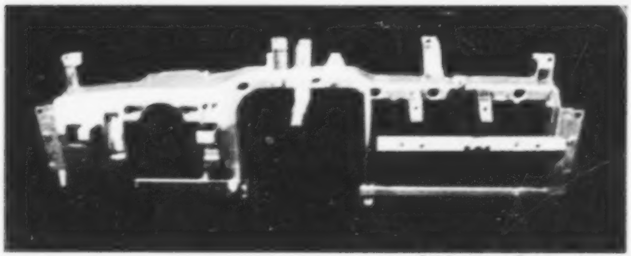

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Figure 13. Magnesium Instrument Panel for the Ford Explorer
Weight: 5.5 kg

Magnesium gradually began to be used in the development of valve covers, pedal brackets, air bag containers, seat frames, transmission housings, sun roof frames and, most importantly, instrument panels for many GM and Ford models, and later for the models of other major manufacturers, such as Fiat, Jaguar, DaimlerChrysler and BMW. Some of these applications are shown in Figures 14 to 16.

More recently, even bigger new parts have been developed, such as the rear tailgate of the three-litre Lupo, developed and produced by Volkswagen, the radiator support developed for the Ford Explorer, and the B pillar on both sides of the vehicle in addition to part of the rear seat of the DaimlerChrysler van. Some of these applications are shown in Figures 17 to 20.

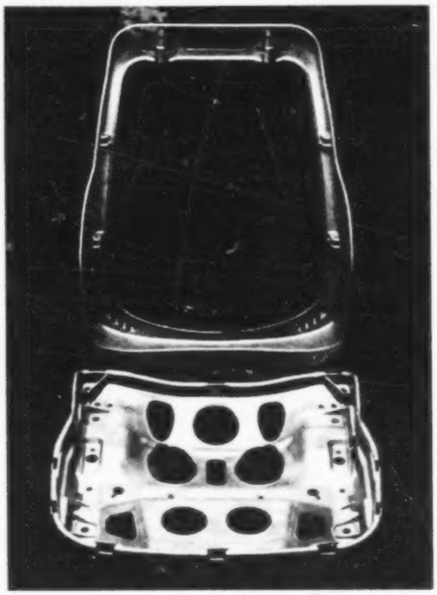

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Figure 14. Magnesium Seat Frame for the Alfa Romeo 146
Seatback weight: 1.0 kg
Cushion support weight: 1.1 kg

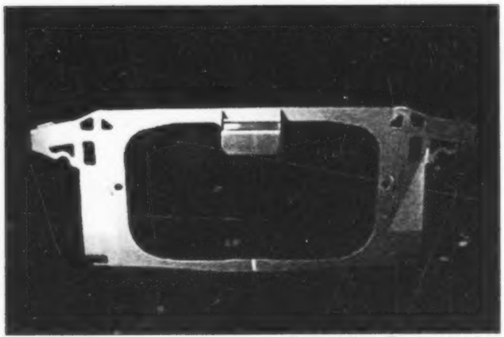

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Figure 15. Magnesium Radiator Support for the Ford F-150 MRS
Weight: 6.1 kg

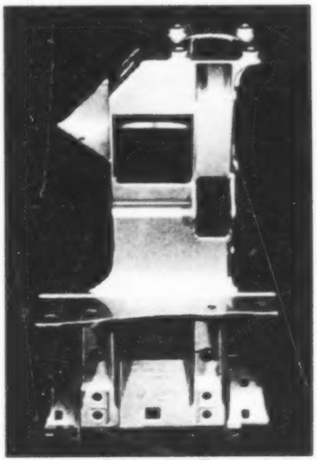

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Figure 16. Magnesium Pedal Bracket for GM's Corvette
Weight: 3.2 kg

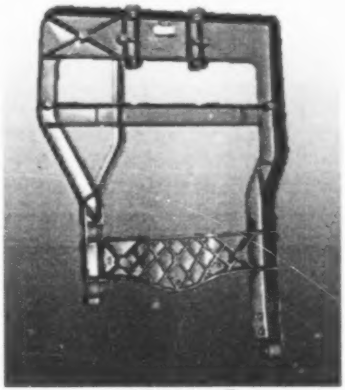

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Figure 17. Rear Seatback (40% Magnesium)
Weight: 1.0 kg

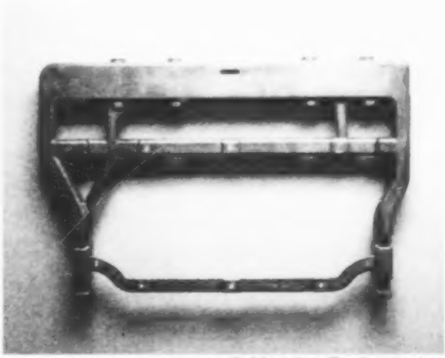

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Figure 18. Rear Seatback (60% Magnesium)
Weight: 1.4 kg

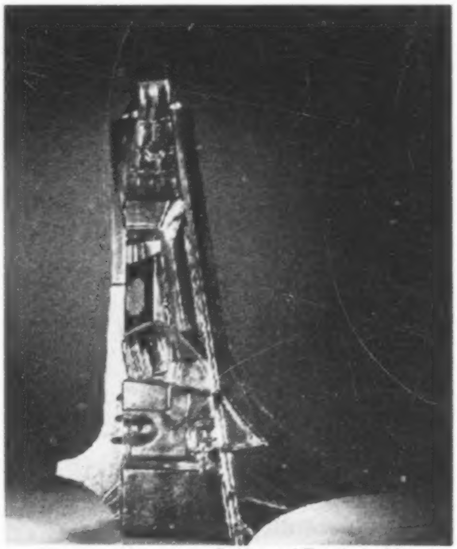

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Figure 19. Magnesium B Pillar for a Rallye Car

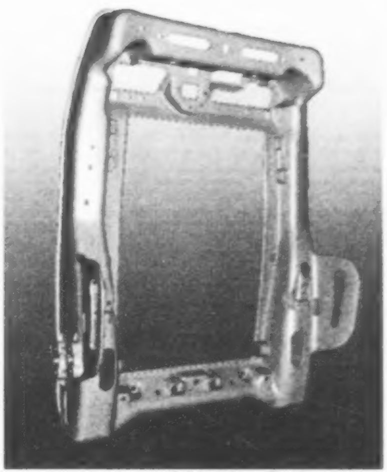

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Figure 20. Magnesium Front Seatback for a Jaguar
Weight: 1.80 kg

As described in Section 2.4, the use of magnesium for seat components has also found favour with automobile manufacturers, such as GM, Ford/Jaguar, Alfa Romeo, DaimlerChrysler/Mercedes Benz, Toyota, and more recently Renault, which are still currently using pressure die cast magnesium seat components. It is also worth pointing out that some manufacturers are working together on R&D projects to make extruded magnesium parts more competitive for applications such as seat frames [11].

3.3.4 Metal forming technologies

In reviewing the main materials used to manufacture seats, it was found that most motor coach seats on the market were made of steel and that aluminum was beginning to be used in some cases. The most regularly used technologies for manufacturing structural components were bending technologies (for steel) and extrusion technologies (for aluminum), while casting technologies were increasingly used to mass-produce footrests, seat trays and armrests.

Only casting technologies are currently developed enough from a profitability standpoint to be considered suitable industrial processes for manufacturing magnesium seats. Several R&D projects are currently looking at laminating processes (sheet steel) and extrusion processes to determine whether the processes themselves and the alloys concerned are suitable for structural applications in the transportation industry and whether they are more cost-competitive.

Magnesium casting processes

Casting produces parts in their final or near-final shapes and dimensions. Magnesium has a high degree of fluidity in its liquid state, which enables it to fill much more complex moulds than aluminum. The main casting processes are described below.

- The most frequently used magnesium casting process is pressure die casting. The two-part mould is reusable and can be used for mass production. The parts have a high degree of dimensional accuracy, which reduces the amount of machining required later. They also have good surface finish and cool quickly. The metal can be injected under low or high pressure. The most frequently used process is high-pressure die casting, particularly for parts intended for the automobile industry.
- There is also a special category of magnesium pressure die casting called semi-solid die casting, or specifically thixotropic moulding or Thixomolding. This process, patented by the American firm Thixomat Corporation, involves the high-speed injection of magnesium granules in a semi-solid (thixotropic) state just below melting point. In this state, the solid particles float in a liquid matrix (slurry) and the magnesium essentially behaves like a plastic. The technique is more similar to the injection moulding process used in the plastics industry than to traditional pressure die casting. The advantage of Thixomolding is that it produces parts with less porosity, thinner walls and better surface finish. This process can be used for mass production and is used in particular to make substitutes for the plastic housings of electronic equipment. Toyota introduced this process in order to manufacture magnesium seat frames for some of its high-end models [14].

In contrast to pressure die casting, there are also gravity die casting processes that allow the metal to flow under its own weight.

- Sand casting is used for small series of parts (usually fewer than 1,000 parts). The mould is made in two parts, corresponding to each half of the model, of compressed sand (to which cement is sometimes added) within a frame. After the model is removed, the two parts of the mould are joined together. Molten metal is injected through ducts. Cooling in sand moulds is very slow, making it possible to control the texture of the metal. The sand mould is destroyed after use, but the sand is reusable. The accuracy of parts obtained using this method varies from average to good. The main advantages of this method are casting speed and a high sand recovery rate. Although this is a recognized and commonly used process for small volumes, the new sand casting process using a vertical mould now makes it possible to produce average to mass quantities at competitive costs.

- Investment casting (lost wax process) is a very old method used mainly for very complex, high-precision parts, usually for the aerospace industry and the military. The model is formed first of all in synthetic wax with extreme accuracy using a conventional casting process. The wax model, which can be very complex, is coated in a refractory material. After the refractory mould hardens, the wax is melted and extracted from the mould. The mould is baked before being filled with the melted alloy and then broken to release the part. Lost-foam casting is another similar technique.
- Many other processes are used, such as plaster mould casting, where moulds are made from plaster and produce thin, complex parts with very high dimensional accuracy.
- Permanent mould casting uses a metal mould, as is done with pressure die casting, except that the metal is gravity poured. The advantages of this process are high-quality surface finish, fairly rapid execution and good dimensional accuracy. This process is midway between the sand casting and pressure die casting processes. It is used to produce moderate numbers of parts (over 1,000), but not for the huge volumes possible with pressure die casting.
- Lastly, there is a hybrid form of casting called squeeze casting, which combines die casting and forging processes. The liquid metal is poured into a preheated half mould and, when it starts to solidify, the upper part of the mould is closed and pressure is applied for the remainder of the solidification period. The process produces high-precision parts with low porosity and enhanced mechanical properties.

However, of all these processes, pressure die casting is the one that has been developed to the highest degree of proficiency and performance. Pressure die cast magnesium accounts for about 95% of the magnesium processed for structural applications.

3.4 ECONOMIC FACTORS

Several economic factors may influence the type of new passenger seat chosen by motor coach manufacturers and operators. By studying recently published studies, it is possible to identify these main factors in terms of both their environmental impact and the costs of acquiring and operating lighter-weight motor coaches.

The first study used as a reference was a study conducted by Martec Ltd. for Transport Canada under the Motor Coach Weight Reduction Program [3]. Published in early 2000, this study clearly identifies the main economic factors to be considered when choosing a new weight-reduction technology.

These economic factors are:

- Lower vehicle life cycle and/or maintenance costs;
- Potential for increasing motor coach payloads;

- Load reduction on the three types of motor coach axles;
- Less pollution produced by motor coaches (suspended particles, fumes, etc.);
- Lower greenhouse gas emissions during the service lives of motor coaches;
- Damage to the road network caused by motor coaches every year.

A quick analysis of these factors shows that their importance varies depending on the role they play in the industry. The first three factors are more important for manufacturers and operators, whereas the last three factors are of greater importance to the Canadian government, which, since the signing of the Kyoto Protocol in 1997, intends to reduce the amount of pollution emitted by motor coaches.

In 2002, IC^2 Technologies Inc., working closely with Multina, conducted a feasibility study on behalf of Meridian Technologies in order to compare the costs of developing and producing magnesium seats for the public transit industry. This study clearly identified the following economic factors influencing the total seat price:

- Cost of developing production equipment for seatbacks, armrests and cushion frames;
- Cost of producing these parts in magnesium;
- Cost of acquiring other parts used to assemble seats after predetermining the parts required for the magnesium solution;
- Cost of assembling magnesium seats;
- Cost saving from having a lower number of parts to manage with the magnesium solution;
- Cost saving resulting from fewer poor quality magnesium parts, compared with the steel solution.

The case study in Chapter 4 takes all of these economic factors into account in order to assess and quantify the competitiveness of a new magnesium seat in relation to alternative solutions. The costs associated with reducing seat weight by one kilogram have also been calculated in order to compare them with the threshold usually deemed acceptable by the industry.

Before going further, it is important to review some the findings of the first feasibility study conducted for Meridian Technologies. The results of this study demonstrated that a pressure die cast magnesium seat could only be competitive with a steel seat at this time if there were especially high annual volumes involved. Because clients are not necessarily prepared to pay a premium for lighter seats, it was concluded that the magnesium solution using pressure die casting was not yet viable.

The choice of manufacturing process is therefore another significant economic factor because it has a huge impact on required volumes and product price. The case analysis in Chapter 4 shows the costs, advantages and disadvantages of solutions using various processes.

It should also be noted that the cost of a process is closely tied to the technology performance factors of the magnesium solution. Choosing the most competitive processing method in terms of price does not necessarily mean that it will be the most competitive in terms of sought-after properties, particularly in terms of weight of components. Indeed, some processes do not produce walls as thin as those produced by pressure die casting. There is likely a compromise to be made between price and performance.

3.5 TRADE AGREEMENTS

Like all of the motor vehicle and trucking industries, the motor coach industry is governed by NAFTA provisions promoting trade between Canada, the United States and Mexico. There are no specific restrictions on the exporting of Canadian motor coach parts, such as seats exported to the United States or Mexico.

However, the situation is different in the urban bus and railway sectors in the United States. Although there is no formal tariff barrier, these sectors, which are heavily subsidized by the United States government, are subject to the *Buy America Act*. Under this Act, the acquisition of new vehicles is eligible for federal government funding only if final vehicle assembly is done in the United States and at least 60% of the parts, in terms of value, are manufactured in the United States. This also explains why several Canadian manufacturers have fabricating and assembly plants in the United States. As well, some non-American corporations import certain products under temporary exemptions.

4. COST-BENEFIT ANALYSIS

This section outlines how the results of a case analysis were used to determine the technical and economic feasibility of small- and large-scale manufacturing of a new magnesium seat for the motor coach market. The best manufacturing process or processes for the first years of production are also identified.

4.1 BACKGROUND

Two other private-sector studies on the development of lighter seats, conducted and funded by Meridian Technologies (a firm specializing in pressure die casting of magnesium), preceded this study. The case study outlined below is a continuation of these initial studies. A brief overview of the objectives and conclusions of each study is included as a guide for the cost-benefit analysis provided further on.

The objective of the first study, carried out in the first quarter of 2001, was to draw up a profile of the passenger seat market for high-speed trains serving North America's major cities. This study determined, among other things, that there are many similarities between a lighter seat for potential use in the railway industry and in the motor coach industry.

After approaching major industry players, such as Prévost Car, Meridian Technologies and seat manufacturer Multina, participated in a second study conducted during the winter of 2002 by IC^2 Technologies Inc. This second study compared the costs of manufacturing and assembling steel passenger seats and magnesium passenger seats for motor coaches. Although the study concluded that the costs of developing a magnesium seat using a pressure die casting process were too high at the time, the potential for a weight reduction of about 375 kg per motor coach (50 to 52 passengers) continued to generate interest.

This study takes this initiative further in order to identify alternatives to pressure die casting that would make it possible to introduce magnesium seats at a lower cost than that determined in 2002. It also looks at other economic and technical factors that might justify such a project.

4.2 MAIN BENEFITS OF LIGHTER WEIGHT

Canada's implementation of the Kyoto Agreement over the next few years is reason to study various ways to reduce energy consumption and greenhouse gas emissions into the atmosphere.

Recent studies carried out primarily in Germany and Canada identify the main benefits associated with reducing the weight of heavy vehicles such as motor coaches. These benefits, already highlighted to some extent in the introduction in Section 1.3, are described below and were compared with the answers obtained in interviews with major motor coach and seat manufacturers and North American operators.

The main objectives of this exercise were (1) to determine whether the benefits of weight reduction identified in previous studies are well understood by engineers who manufacture seats and motor coaches and (2) to validate whether managers responsible for motor coach operations take these benefits into account when acquiring new vehicles. This comparison will help to more effectively co-ordinate the development strategy for a new type of seat.

Benefits identified in Europe

In January 2003, the International Aluminium Institute published the conclusions of a European study entitled Energy Savings by Light-Weighting, conducted by the Energy and Environmental Research Institute in Heidelberg, Germany [14].

According to figures published by the International Energy Agency (IEA), the transportation industry consumes close to 26% of the world's energy production and nearly 58% of fuel production. It is therefore important to identify ways to reduce this energy consumption and emission of greenhouse gases.

By taking specific reductions in energy consumption to obtain a 100-kg weight reduction into account and comparing them with the life cycle costs for the main types of vehicles using highways and railways, this study demonstrated the following:

- Reducing the weight of a vehicle reduces the consumption of energy required to propel the vehicle (energy consumption is directly proportional to weight, except in the case of aerodynamic resistance);
- Lower weight reduces the environmental impact associated with vehicle use throughout what might be called the energy chain (i.e., from the supply network of gas stations to energy conversion in the engine);
- A vehicle's energy consumption is determined by the efficiency of its components (transmission and engine) and the energy source used (gasoline, electricity, hybrid energy source, etc.);
- Energy savings related to a 100-kg weight reduction depend on vehicle use. For example, the biggest energy savings can be obtained for vehicles making frequent stops and starts, such as urban buses;
- Vehicles travelling at a constant speed, such as motor coaches, which are exposed to substantial aerodynamic resistance and little acceleration resistance, have a low potential for energy savings.

Benefits identified in Canada

As mentioned in the background information provided in Section 1.3, TDC launched a motor coach weight reduction project in 1999 to be carried out jointly with industry partners. Now that two of the first three phases have been completed (January 2000 and 2004), this project seeks to identify potential design concepts for reducing motor coach weight that would help manufacturers build lighter-weight vehicles and help operators solve operational and regulatory problems related to surplus weight.

In Phase 1, the following four main benefits of weight reduction were identified:

- Reduced fuel consumption (aerodynamics, drag, weight reduction and mechanical efficiency);
- Lower maintenance costs for parts (synonymous with increased reliability);
- Reduction in polluting emissions;
- Less wear and tear on road infrastructure.

The first two benefits have a direct impact on vehicle life cycle costs for operators, while the last two have a more significant impact for governments in terms of compliance with the Kyoto Agreement and minimizing Canada's road network maintenance costs.

Another significant benefit, described in Section 1.3, is that lower motor coach weight helps solve the **recurring problem of axle overload** in order to meet provincial standards applying to heavy vehicles.

Other benefits often identified are increased vehicle load capacity (when axle overload is not a problem) and reduced braking time for lighter vehicles.

Lastly, because more and more motor coaches are being used in urban areas (shuttle services, suburban-downtown transit links, city tour buses, etc.) and because they usually make very frequent starts and stops, lower weight has a significant impact on gasoline consumption.

Other identified benefits

During the development of a preliminary design as part of the study conducted in 2002 by IC^2 Technologies Inc. and during the interviews with seat manufacturer Compin in Belgium, the following other significant benefits were identified. These benefits were not related solely to magnesium use, but rather to the use of die cast parts, as opposed to folded sheet metal parts:

- Greater benefits in terms of resonance frequency and seat rigidity;
- Incorporation of more components and a reduction in the number of parts required per seat;
- Lower assembly time resulting in lower manufacturing costs;
- Ease of handling of lighter-weight seats;
- Potential for minimizing the bulkiness of seat frames in order to maximize space available to passengers.

Industry perceptions and viewpoints

When the answers of industry representatives surveyed for this study were reviewed, it was found that lighter-weight passenger seats generated interest, but did not seem to be a priority as long as clients did not make them a requirement. Lighter weight was usually less important than seat comfort over long distances and the potential for maximizing the amount of space available between each row of seats. An industry representative said that people in the industry thought that passenger seat comfort and seats with less bulk were discriminating factors in choosing a supplier.

Another important viewpoint expressed by both manufacturers and operators was that a total seat weight reduction of about 375 kg was somewhat minimal compared with the total estimated weight of 20,000 kg for a loaded motor coach. In their routine analyses of operating costs, they thought that only the combined effect of lighter-weight seats and lighter weight for all other structural components of a motor coach would help to significantly and identifiably reduce the maintenance costs of these vehicles.

It was also pointed out that manufacturers were under immense pressure from their clients to build lighter vehicles without increasing manufacturing costs. Since the current purchase price of a motor coach is close to $500,000, an amount representing nearly one third of the operating costs of a motor coach during its life cycle, it is easier to understand the technological and economic factors facing manufacturers and why operators seek lower purchase prices.

In short, it was confirmed in the consultations conducted during this study that the motor coach industry is interested in significant weight reductions for new vehicles, but that operators are mainly concerned with lower maintenance and operating costs for their vehicle fleets. It is not surprising to find that the environmental and economic benefits of reducing CO_2 emissions or minimizing road network maintenance costs are not a priority for the industry.

The industry survey found there was considerable interest in developing lighter-weight seats, provided the seats:

- Do not cost more to buy;
- Are less bulky than seats already on the market;
- Have lower maintenance costs;
- Reduce to a minimum sources of metallic noise and unpleasant vibrations over long distances;
- Have contours that clients find attractive;
- Are equipped with seatbelts with three attachment points.

Some operators also said they were interested in lighter-weight seats only if more in-depth case studies with actual prototypes demonstrated that significant savings could be achieved by using these seats over a long time period. Some western Canadian charter motor coach operators pointed out that European tourist groups preferred motor coaches equipped with seatbelts.

4.3 IDENTIFICATION OF MANUFACTURING TECHNOLOGIES

The potential for lighter-weight seats cannot be realized without identifying a suitable manufacturing technology. As pointed out in Section 4.1, the study conducted in 2002 by Meridian Technologies and Multina concluded that the cost of developing magnesium seat manufacturing equipment using a pressure die casting process was too high. It was therefore important to identify other available manufacturing processes and to compare their costs with those of pressure die casting technology.

Based on Section 3.3.4, which outlines the main casting technologies available on the market, the following technologies were selected for this assessment:

- Sand casting;
- Permanent mold casting;
- Pressure die casting using a horizontal press (conventional method);
- Pressure die casting using a vertical press; and
- Thixomolding.

Sand casting technology was selected because it is already currently used to manufacture prototypes and small, medium and large quantities of parts for various transportation industries (automobile, truck, train and aircraft). Permanent mould casting technology was selected because some motor coach manufacturers already frequently use this technology to manufacture cast aluminum parts, such as armrests, luggage rack supports and wheel rims. However, to obtain similar mechanical properties as those that would be obtained using the pressure die casting or Thixomolding processes, the parts must be heat-treated after they have been moulded.

As for the lost-foam technology, requests for bids were sent to two different suppliers, but neither submitted a bid. The first supplier assessed the parts as being too complex, and the second supplier had temporarily shut down operations because of a recent incident in its foundry.

The authors also thought the cost of the pressure die casting process should be reviewed in order to establish a reference point in relation to other submitted costs and to verify the impact of cost fluctuations of magnesium alloys in recent years. Pressure die casting using vertical presses rather than conventional horizontal presses was also selected in order to take certain technological advances into account.

Table 20 is a list of the submitted technologies. The tooling development costs and production costs involved in manufacturing parts for a new magnesium seat are set out in Section 4.4. In the case of permanent mould casting, a bid for aluminum parts was also requested so that a hybrid solution combining magnesium and aluminum could be considered, if necessary, for cost reasons.

Table 20. Technologies Assessed for Lighter-Weight Seat Design Purposes

Process	**Mg**	**Al**	**Number of Suppliers Contacted**	**Suggested Alloys**
Gravity Casting Processes				
Sand casting	X		2	AZ91
Permanent mould casting	X	X	3	AZ91, A413 and A380
Pressure Die Casting Processes				
Horizontal press	X		1	AM60B and AJ62L
Vertical press	X		1	
Thixomolding	X		2	
Number of suppliers			7	

N.B.: All of the contacted suppliers are located in North America.

4.4 CASE STUDY

The following case study presents the main costs involved in developing and manufacturing magnesium passenger seats and compares these costs with the usual costs involved in manufacturing steel seats currently installed in most motor coaches in North America. The cost of developing and manufacturing a hybrid seat combining aluminum and magnesium is also included in order to validate whether a hybrid approach can make it easier to market lighter-weight seats.

4.4.1 Data sources

Aside from the seatback and lower cushion frame costs submitted by various suppliers contacted during the call for bids, all other seat manufacturing-related costs (assembly and inspection costs, hardware costs, administrative expenses, etc.) were taken directly from the feasibility study conducted by IC^2 Technologies Inc. in 2002, with an annual adjustment of 2% added on. All of these costs were then assessed by Multina based on the steel seat currently used by Prévost Car, shown in Figure 22.

4.4.2 Costs to be taken into consideration

The following are the main costs with a potential impact on the total cost of manufacturing a passenger seat:

- Cost of manufacturing structural components (seatback, seat, armrest, footrest and headrest);
- One-time costs (production equipment and assembly and adjustment jigs);
- Cost of hardware required to assemble all seat components;
- Cost of assembling seats requiring human input (operator, inspector, controller, buyer, etc.);
- Seat upholstering and fitting costs;
- Costs of surface finishing of parts and/or surface treatment of parts against corrosion;
- Costs of heat treatment and straightening fixture, if necessary (for example, for sand casting and permanent mould casting).

Since the study objective was to identify a processing alternative to pressure die casting so that magnesium seats could be marketed at affordable prices, this analysis deals only with production costs for the two main seat components, i.e., the seatback and lower seat.

The rationale for this approach was that the cost of developing and producing these two components using pressure die casting accounted for over 60% of the cost of a new seat, based on the study carried out in 2002, and was the only area where the magnesium solution was not competitive.

4.4.3 Seat design used for the case study

The design used for the case study was developed as part of the feasibility study conducted for Meridian Technologies, which compared the cost of developing a steel seat with that of a new magnesium seat. This magnesium seat design is shown in Figure 21. The steel seat design used for this study is currently used by Prévost Car and shown in Figure 22.

The magnesium design consists of a single moulded part for the lower portion of the seat, two seatbacks, armrests and an extruded part for anchoring the seat to the motor coach floor. The monocoque cushion support is the key component of this design because it is the part onto which the seatbacks, armrests, extruded parts and various seat position adjustment mechanisms are assembled. This cushion support is attached to the motor coach in two different places. Its aisle side end is attached to the extruded anchoring support bolted directly into the floor, while its other end is bolted directly to the inside wall of the motor coach below the windows.

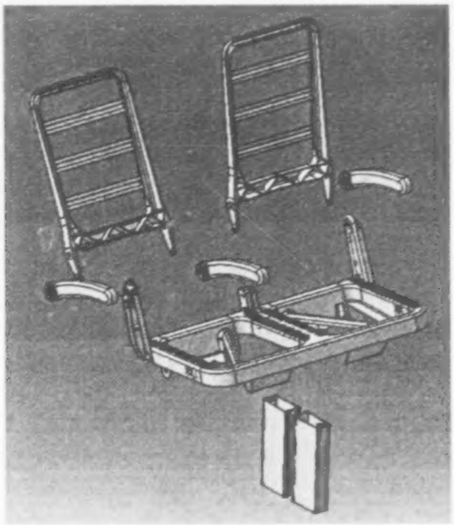

Figure 21. Monocoque Passenger Seat Design Used by Multina and Meridian Technologies (2002)

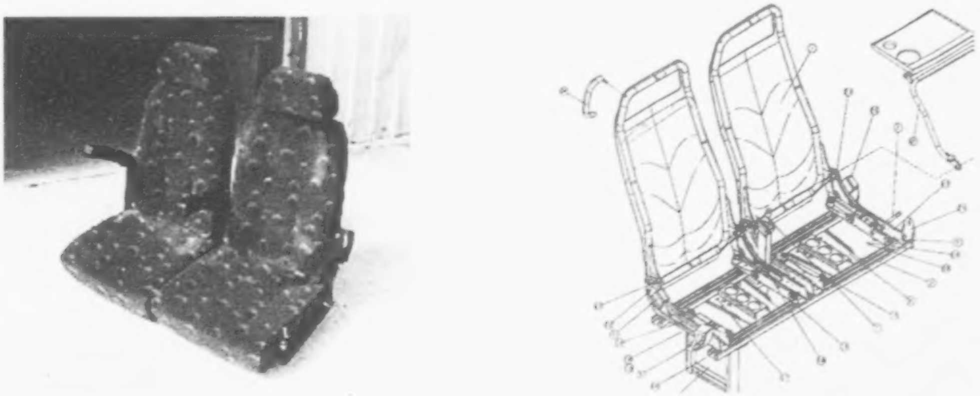

Figure 22. Steel Seat Currently Used by Prévost Car and as a Reference for the Case Analysis

Extruded parts are used for the lower support frame of the seat because this part is subject to considerable stress during a collision. To minimize the risk of injury to passengers projected forward during a major collision and additional costs related to anti-corrosion coatings, the proposed design used extruded aluminum parts with better mechanical properties than cast magnesium parts. It was confirmed in our consultations with various seat and motor coach manufacturers that this was an appropriate decision both technically and economically.

It should be pointed out that magnesium parts were designed to repel accumulations of water or other liquids in order to minimize the risk of galvanic corrosion, and that an objective of the current design was to prevent magnesium parts from being directly exposed to passengers and thus avoid additional costs related to surface protection for these parts.

4.4.4 Estimated weight reduction

According to the data in the feasibility study conducted for Meridian Technologies, this magnesium design (two-seat bench) results in a weight reduction of more than 20 kg, or a decrease of up to 45%, compared with the complete (whole seat assembly) steel solution used by Prévost Car.

However, since structural analyses have not yet been carried out on this seat design and since the final weight will vary depending on the manufacturer's decision to design the seat with or without three-point seatbelts, a weight reduction of 15 kg per double seat was selected as a working assumption. This represents a total reduction of about 375 kg for a 50-passenger motor coach. This assumption seems conservative since over 5 kg of magnesium can be added to the design to meet client technical specifications.

For case analysis purposes, this figure is used as a reference in calculating reduced CO_2 emissions and estimated reduced wear and tear on main motor coach components and the road network.

4.4.5 Description of cost reductions associated with magnesium seats

This section outlines the main conclusions of the study conducted in 2002 for Meridian Technologies. Some of the data in this study are mentioned in general terms to protect the confidentiality of the submitted information.

The methodology used for this study was very simple. From the Multina line of passenger seats, Multina technical employees selected a steel seat similar to those usually manufactured for motor coaches. A list was then drawn up of all the tasks performed by technical and administrative employees during the various phases of seat assembly.

In the meantime, Multina engineers used a passenger seat already used by Prévost Car in order to quantify the tooling development costs and production costs of steel seat parts currently available on the market. The final phase of this activity involved the preparation of the magnesium design shown in Figure 21 and a second magnesium seat design similar to those built by European seat manufacturers (cushion support for two seats divided into two pieces and bolted to two extruded aluminum bars).

The following costs were identified for the three solutions that were studied:

- One-time costs of developing manufacturing equipment;
- Units costs of parts;
- Cost of inspecting parts;
- Administrative costs for the purchase and inspection of delivered parts;
- Costs related to delivery of substandard parts;
- Cost of hardware required for assembly (screws, cylinders, seat adjustment mechanisms, fabric, cushions, etc.);
- Cost of armrests, footrests and headrests.

The study also took the following into consideration for each of the three designs solutions studied:

- Final weight of each design;
- Total number of parts required;
- Total number of suppliers required;
- Usual rejection rate for steel parts, compared with that for magnesium parts;
- Number of quality inspectors required during assembly of a predetermined number of seats;
- Number of assembly problems eliminated through greater dimensional accuracy of cast parts.

The following were the main conclusions drawn from the comparison of costs for the monocoque magnesium solution, compared with those of the steel solution:

- 10% fewer structural parts were required to assemble the monocoque magnesium seat;
- Both the number and cost of hardware items for the magnesium solution were 50% less, compared with the steel solution;
- The number of suppliers for the magnesium solution was lower by more than 25%;
- The monocoque magnesium solution took 12% less time to assemble;
- The number of rejected parts in the case of the magnesium solution dropped by 10%;
- For the production of large quantities each year over five years, the cost to the manufacturer in terms of technical and administrative employees assigned to seat manufacturing operations could be more than 30% lower than the usual cost of manufacturing a similar steel seat.

In short, seat manufacturers can obtain significant savings in terms of labour and other associated costs if a new magnesium seat is manufactured using casting technologies and provided annual sales volumes are sufficient. However, the cost of tooling development to produce pressure die cast parts is an economic hurdle to be overcome in order to obtain these savings.

In order to take into account the reductions in assembly time, number of parts, labour and other factors listed above, the Multina engineers calculated an estimated saving of $2.00 per magnesium double seat (for the sales volumes stated in Table 21 for the first eight years of production), compared with the cost of assembling an equivalent steel seat.

4.4.6 Projected sales volumes

The sales volumes required for the case study were based on the following projections:

- As described in Chapter 2, the estimated Canadian/American market for new motor coaches is 1,500 units per year, based on the most conservative analyses (which means the market would return to its usual average after a period of strong growth);
- Magnesium seats will be targeted initially at the high-end motor coach market;
- The market could be gradually expanded to include Mexico, where the annual number of new motor coaches is about 1,900 units;
- A new product can usually be expected to obtain a maximum market share of 2% in its first year of full production;
- An average of 25 double seats per bus.

Based on these projections and using a rather conservative approach, estimated volumes were determined for the production of initial prototypes and the first eight years of mass production. The estimated costs in Table 21 are based on these volumes.

Table 21. Projected Sales Volumes for the First Eight Years

Development and Marketing Phase		**Estimated Annual Volume**			
		Number of Buses Equipped with New Seats	**Number of Double Seats**	**Monocoque Cushion Frames**	**Seatbacks**
Prototypes	Yr 0	1	**25**	x 1 unit	x 2 units
Commercial launch	Yr 1	10	**250**		
Production	Yr 2	20	**500**		
	Yr 3	40	**1,000**		
	Yr 4	60	**1,500**		
	Yr 5	100	**2,500**		
	Yr 6	150	**3,750**		
	Yr 7	200	**5,000**		
	Yr 8	300	**7,500**		

4.4.7 Analysis of the cost of various technologies

For each technology listed in Table 20, various suppliers were asked to submit bids on the two main parts of the magnesium seat design. The specifications clearly indicated that they were to submit estimates for manufacturing the seat initially designed for the die casting technology and to indicate whether there were any limitations regarding their casting technology on the production of these parts in terms of wall thickness and part size.

All of the suppliers responded as requested, except one of the two firms asked to submit estimated costs of various gravity casting technologies. This firm initially refused to provide prices for producing the two parts using a permanent mould casting process because it thought the parts were too complex and involved too high a risk to produce. After several discussions, the firm's engineers finally agreed to submit a cost estimate, but only for the project. They also advised against using a lost-wax casting process for this application. However, the other supplier contacted about these same processes promptly submitted prices for both sand casting and permanent mould casting.

The submitted quotes were deemed reliable and representative of actual production equipment development costs and production costs of parts if the magnesium passenger seat design were to be launched with a short deadline. In some cases where there were doubts as to the reliability of a source, the prices were checked with other suppliers. Moreover, the die casting firms that were contacted had been involved in magnesium and/or aluminum processing for over 20 years and tended to submit prices on the high rather than low side during a call for bids of this type.

Tooling development costs and cost of parts

In Table 22, tooling development costs are provided for each technology that was studied. It should be mentioned that vertical injection pressure die casting presses with sufficient capacity to cast monocoque frames were still being developed at the time of the study. However, the technology should be commercially available shortly. The Thixomolding presses currently available on the market do not have enough capacity to cast monocoque frames, and it appears that none will be available in the short term.

Table 22. Cost of Tooling Development for Each Process

Process	Monocoque Cushion Frame		Seatback Frame		Total Cost
	Cost	Service Life (units)	Cost	Service Life (units)	
Gravity Casting Processes					
Sand casting	$ 29,000	< 2,000	$ 25,000	< 2,000	$ 54,000
Permanent mould casting	$112,800	70,000	$ 57,900	70,000	$170,700
Pressure Die Casting Processes					
Horizontal press	$420,500	50,000	$248,000	50,000	$668,500
Vertical press	N/A[a]	50,000	$235,000	50,000	N/A
Thixomolding	N/A[b]	50,000	$386,100	50,000	N/A

[a] Presses of sufficient capacity are being developed.

[b] No press of sufficient capacity on the market.

Table 22 shows that the cost of tooling development for pressure die casting processes is substantially higher than that for gravity casting processes. However, as shown further on, the production unit costs are considerably lower, which justifies their use for mass production.

Similarly, Table 23 shows the average cost of the two main seat components based on projected sales volumes (costs in the case of pressure die casting processes are not based on a given annual volume, but on the cumulative volume corresponding to the total for the first eight years). Since a complete solution cannot be obtained by using vertical injection pressure die casting processes and Thixomolding processes, each of these processes was combined with a conventional pressure die casting process in order to manufacture the monocoque frame.

Table 23. Cost of Producing Parts for Each Manufacturing Process

Casting Process	Prototype	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8
	Unit Costs ($) per Annual Volume Produced								
Monocoque cushion frame	25	250	500	1,000	1,500	2,500	3,750	5,000	7,500
Sand casting	310	290	278	274	272	272	272	272	272
Permanent mould casting	128	115	109	104	104	100	100	100	100
Horizontal pressure die casting (HPDC)[a]	65	65	65	65	65	65	65	65	65
Vertical pressure die casting (VPDC)[b]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Thixomolding[c]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Seatback frame	50	500	1,000	2,000	3,000	5,000	7,500	10,000	15,000
Sand casting	170	158	156	155	155	155	155	155	155
Permanent mould casting	78	66	64	64	61	61	61	61	61
HPDC[a]	45	45	45	45	45	45	45	45	45
VPDC[b]	64	41	41	41	41	41	41	41	41
Thixomolding[a]	20	20	20	20	20	20	20	20	20
Total for double seats[d]	25	250	500	1,000	1,500	2,500	3,750	5,000	7,500
Sand casting	650	607	591	584	584	584	584	584	584
Permanent mould casting	285	248	238	233	227	222	222	222	222
HPDC[a]	156	156	156	156	156	156	156	156	156
HPDC + VPDC[a,e]	195	148	148	148	148	148	148	148	148
HPDC + Thixomolding[a,f]	106	106	106	106	106	106	106	106	106

[a] Suppliers of large-volume processes preferred to calculate a unit price based on annual average volume over the first eight production years.

[b] Presses with sufficient capacity are being developed.

[c] No press with sufficient capacity on the market.

[d] A double seat consists of a cushion frame and two seatback frames.

[e] Monocoque cushion frame manufactured using a conventional (horizontal) pressure die casting process and seatback frames manufactured using a vertical injection pressure die casting process.

[f] Monocoque cushion frame manufactured using a conventional (horizontal) pressure die casting process and seatback frames manufactured using a Thixomolding process.

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Horizontal pressure die casting (HPDC)[a]	65	65	65	65	65	65	65	65	65
Vertical pressure die casting (VPDC)[b]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Thixomolding[c]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Seatback frame	**50**	**500**	**1,000**	**2,000**	**3,000**	**5,000**	**7,500**	**10,000**	**15,000**
Sand casting	170	158	156	155	155	155	155	155	155
Permanent mould casting	78	66	64	64	61	61	61	61	61
HPDC[a]	45	45	45	45	45	45	45	45	45
VPDC[b]	64	41	41	41	41	41	41	41	41
Thixomolding[a]	20	20	20	20	20	20	20	20	20
Total for double seats[d]	**25**	**250**	**500**	**1,000**	**1,500**	**2,500**	**3,750**	**5,000**	**7,500**
Sand casting	650	607	591	584	584	584	584	584	584
Permanent mould casting	285	248	238	233	227	222	222	222	222
HPDC[a]	156	156	156	156	156	156	156	156	156
HPDC + VPDC[a,e]	195	148	148	148	148	148	148	148	148
HPDC + Thixomolding[a,f]	106	106	106	106	106	106	106	106	106

[a] Suppliers of large-volume processes preferred to calculate a unit price based on annual average volume over the first eight production years.

[b] Presses with sufficient capacity are being developed.

[c] No press with sufficient capacity on the market.

[d] A double seat consists of a cushion frame and two seatback frames.

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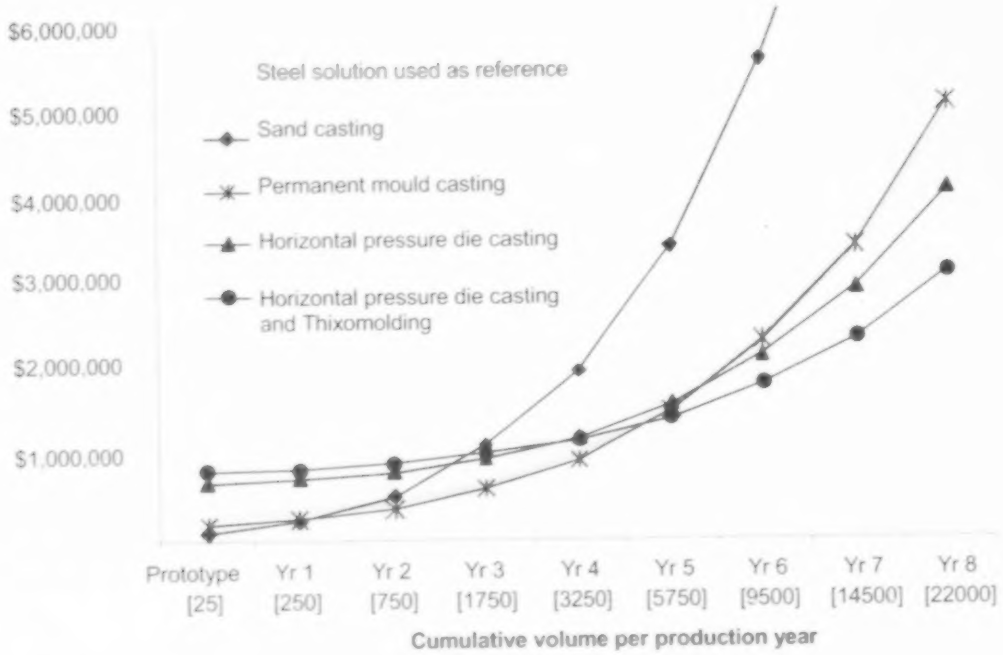

Figure 23. Cumulative Costs of Producing Double Seats (Equipment and Production) per Selected Casting Process

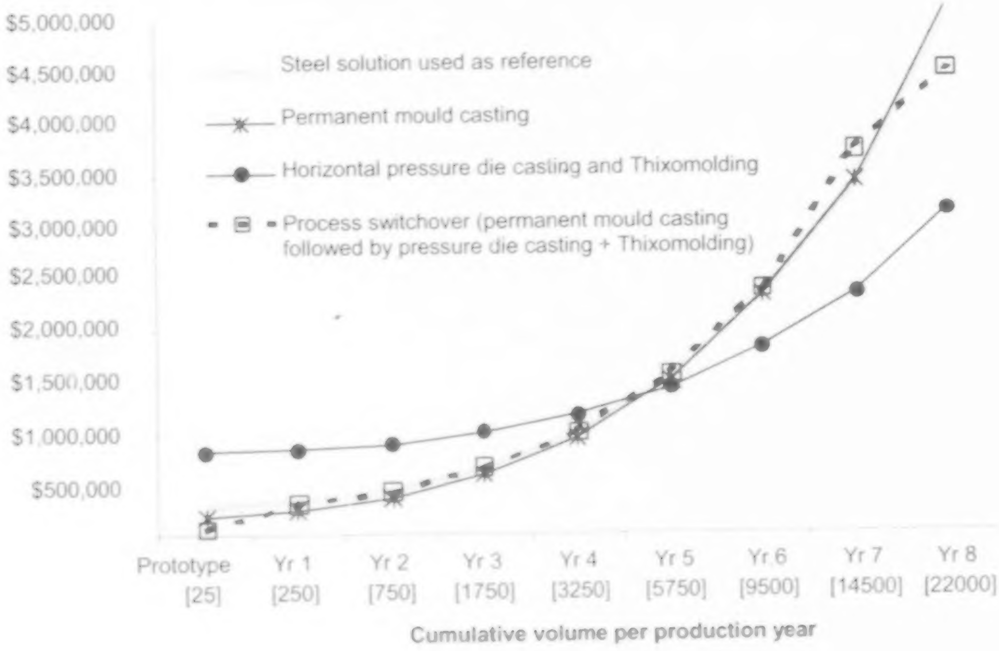

Figure 24. Cumulative Costs of Producing Double Seats (Equipment and Production) per Selected Scenario

Figure 23 shows the year-to-year changes in the total accumulated cost of each solution (initial equipment and total cost of produced parts) based on the sales projections in Table 21. The graph identifies the process requiring the least amount of capital over the years when taking into consideration, for financial analysis purposes, the value of money over time.

The following were the findings when these data were analysed.

- For the building of prototypes and the validation phase, sand casting was the process requiring the least amount of investment;
- For a cumulative volume of about 5,000 to 5,250 double seats, the permanent mould casting process offered the lowest costs with a minimum of investment;
- Based on the total cumulative cost (equipment and production costs), the magnesium solution using permanent mould casting required less capital than the conventional steel solution, up to a total volume of between 8,000 and 9,000 units (although equipment for the steel solution was amortized over a much longer service life, the equipment acquisition cost of the steel solution was higher than that of the permanent mould casting solution);
- As soon as the total volume produced exceeded 5,250 units, the option combining the conventional pressure die casting process for the monocoque cushion frame with the Thixomolding process for the seat frames offered the lowest cost. However, this option required two suppliers rather than one;
- The option using vertical injection pressure die casting was less expensive than conventional pressure die casting and was the second best option for large volumes. Since larger capacity presses will soon be available on the market, it would be worthwhile to assess a complete solution using this technology.

The conclusion can be made that for the first six years of production (based on the projected volumes in Table 21), the permanent mould casting process is the best option, given the uncertainty about volumes. Beginning in the seventh year, if demand continues to grow as forecast, a switchover to the solution combining pressure die casting and Thixomolding could be considered in order to benefit from the competitiveness of these processes for large volumes. In fact, the projected volume in the sixth year (3,750 double seats, or some 150 motor coaches) is sufficient, if maintained in the following years, to justify a switchover to pressure die casting processes.

Figure 24 shows the changes in total cumulative cost for this switchover scenario at the start of the seventh year of production (prototyping using sand casting and the first phase of permanent mould casting production followed by a long-term production phase combining pressure die casting and Thixomolding). Owing to the high cost of equipment, there is a significant cost increase when the pressure die casting and Thixomolding processes are introduced, but the substantial accumulated savings in the cost of parts ensures that the total cumulative cost falls quickly below that of the steel solution used as a reference beginning in the following year, and also becomes clearly lower than the cost of permanent mould casting. In other words, the additional costs generated by the process switchover in the seventh year are fully absorbed a year after the change. This scenario therefore seems to minimize investment risks as well as offer the best cost compromise.

The processes described above were chosen simply on the basis of the initial objective, which was to identify and validate the most economical way of manufacturing magnesium seats. The case analysis clearly shows that the permanent mould casting process is the one that will make magnesium competitive with the steel solution. As soon as annual volumes reach 3,750 double seats per year, it would be appropriate for seat manufacturers to switch over to pressure die casting or Thixomolding, depending on their specific economic criteria and changes in these technologies in the coming years.

4.4.8 Comparison of costs with those of the steel solution

Based on the above data, it is possible to estimate a net unit cost for a magnesium double seat and to compare this cost with that of the equivalent steel solution currently used in the industry.

To obtain a meaningful comparison, the following assumptions must be made:

- Equipment costs and parts manufacturing costs are included in the calculation;
- Equipment costs are amortized over the service life of the equipment (expressed in units produced);
- The lower assembly cost of the magnesium solution in relation to the steel solution is included in the calculation;
- The cost of armrests and the support frame for these armrests is included in the calculation (in the case of the magnesium solution, the armrests are aluminum and the support frames are already incorporated into the monocoque cushion frame);
- For calculation purposes, machining costs are not included.

Figure 25 shows the change in net unit cost of manufacturing a complete double seat using a permanent mold casting process over the long term and the switchover scenario described above (the cost of both compared with that of the steel solution used as a reference). The equipment cost of the permanent mould casting process used over the long term was amortized over the equipment's actual service life, i.e., 70,000 units. In the case of the option involving a switchover (or anticipated switchover) to another process, the equipment cost for permanent mould casting was amortized over the total volume of the first six years, i.e., 9,500 units, whereas the depreciation on equipment for pressure die casting and Thixomolding is spread over the full service life of the equipment, or 50,000 units.

On closer analysis, Figure 25 shows that where small quantities are concerned (up to 1,000 double seats or up to 40 motor coaches), the manufacturing of magnesium seats using the permanent mould casting process (as a long-term solution) involves an additional cost of 10 to 15%, compared with the steel solution, and a supplementary cost of 4% in the case of larger volumes (2,500 double seats or 100 motor coaches or more per year). Over the eight-year period, the average unit cost represents an additional cost of approximately 5%, compared with the cost of the steel solution used as a reference. In terms of cost per kilogram of less weight (metric measurements are often used in weight reduction analyses), this represents an additional cost of $2.33/kg for volumes of 250 seats per year and a slight supplementary cost of $0.66/kg for larger volumes.

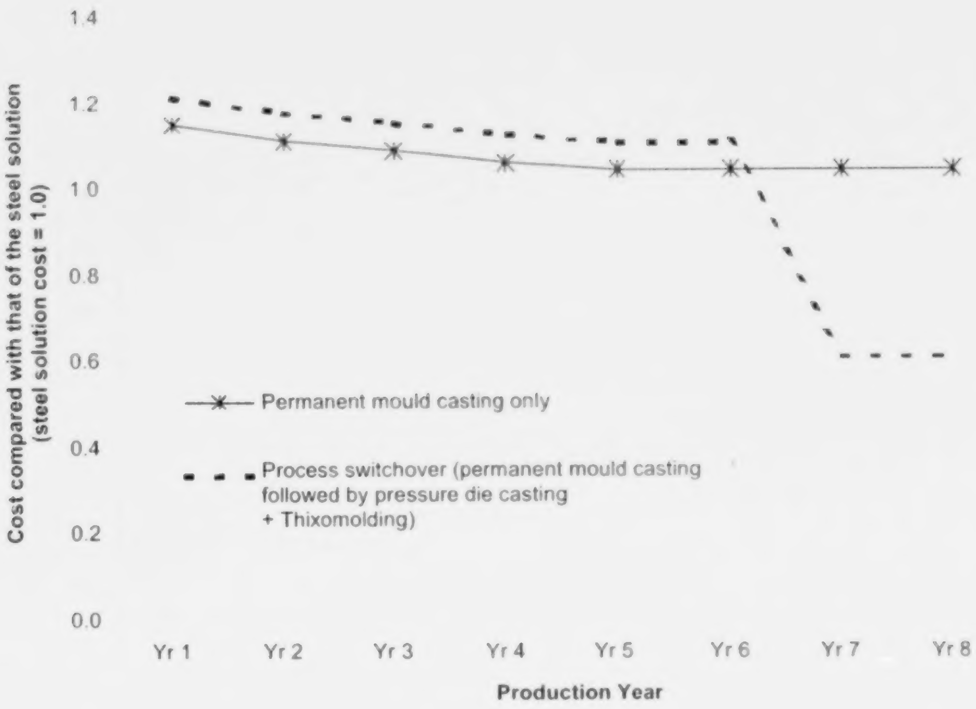

Figure 25. Net Unit Cost of a Complete Double Seat, Compared with the Steel Solution Used as a Reference

In the scenario involving a process switchover along the way (permanent mould casting followed by pressure die casting and Thixomolding), the cost of the permanent mould casting equipment is amortized over a smaller quantity, which has an impact on costs. Over the six years of production using this process, the total additional cost per unit would vary between 20% and 10%. If the average cost of parts for these six years of production using the permanent mould casting process is taken into account, the supplementary cost is about 12%, compared with the cost of the steel solution. The numbers become more interesting when the pressure die casting processes are introduced. The option combining pressure die casting and Thixomolding can reduce costs by nearly 40%, compared with the steel solution.

In terms of cost per kilogram of less weight in this scenario, this represents an additional cost of $3.40/kg of less weight when a permanent mould casting process is used for annual volumes of 250 double seats (10 motor coaches), compared with a saving of more than $6.00/kg when pressure die casting processes are used.

Even starting in the first year of production, these data compare favourably with the cost limit of $1.75/kg of less weight cited by some motor coach manufacturers.

4.4.9 Impact on life cycle cost

To assess all of the benefits of magnesium passenger seats, it is important to quantify the main benefits associated with lighter weight identified above in Section 4.2.

Given that the specifications submitted to the suppliers were based on an optimized design using pressure die casting, the wall thicknesses of parts produced with the permanent mold casting process will very likely need to be increased slightly to take limitations of the process into account. This could have a slight impact of 10% to 15% on the weight saving obtained with this solution.

Based on Transport Canada data, the reductions obtained for four main life cycle components were assessed (see Table 24).

Table 24. Impact on Life Cycle Cost

Life Cycle Cost Component	**Lower Costs Resulting from a Weight Reduction of 375 kg per Motor Coach**	
	Annual saving per motor coach	Saving per motor coach life cycle (15 years)
Gasoline	$295	$4,425
Brake and tire wear	$110	$1,650
Road infrastructure	$264	$3,960
Polluting emissions	$176	$2,640
Total	**$845**	**$12,675**

Table 24 summarizes the economic impact resulting from motor coach weight reduction attributable to magnesium seats. The following were the main assumptions used for these calculations:

- Estimated annual number of kilometres driven per motor coach: 140,625 km;
- Fuel consumption of 2.5 km/litre;
- Cost per litre of fuel of $0.70/litre;
- Weight reduction of 1,000 kg reduces fuel consumption by 2%;
- Estimated saving in brake and tire wear and tear of $0.0025/km per bus when weight reduced by 1,200 kg;
- Estimated saving in road infrastructure damage of $0.006/km per bus when weight reduced by 1,200 kg;
- Estimated reduction in environmental damage attributable to polluting emissions of $0.004/km per bus when weight reduced by 1,200 kg.

Although they seem relatively minimal, the direct savings in life cycle costs for motor coach operators (cost of gasoline and of wear and tear on brakes and tires totalling $405 per year per motor coach) make it possible, in the case of low production volumes of 20 motor coaches per year ($875 per motor coach), to recover the additional cost per kilogram of a magnesium solution in about two years and in less than one year for annual volumes of 100 motor coaches ($250 per motor coach). For operators, a motor coach equipped with magnesium seats produces a direct saving of some $6,000 during the vehicle's service life. For major operators with fleets of several hundred motor coaches, this translates into several million dollars of additional profit.

In terms of reduced CO_2 emissions, the impact of a weight reduction of 375 kg per motor coach is relatively small – about 1.14 tonnes per year, or some 17 tonnes per motor coach during its estimated service life of 15 years. However, this lighter-weight solution can be employed in complementarity with other technical solutions for achieving lighter weight and thus reduce CO_2 emissions.

4.4.10 Cost of a hybrid aluminum and magnesium solution

For the first phase of production, it is worthwhile to compare the cost of an all-magnesium solution using a permanent mould casting process with that of a hybrid solution combining aluminum and magnesium. Table 25 compares the cost of manufacturing parts for the magnesium solution with those of two different hybrid solutions (with a permanent mould casting process used in all cases).

The cost of the first hybrid solution was obtained by calculating the cost (parts manufacturing only) of a magnesium monocoque base combined with two aluminum seatbacks, while the cost of the second hybrid solution was obtained by combining an aluminum monocoque base and two magnesium seatbacks. The weights for these two hybrid solutions were 8.7 kg and 9.9 kg, respectively, compared with 5.9 kg for the all-magnesium solution. Assuming that magnesium passenger seats produce a weight saving of 15 kg per double seat, the savings would be 11.1 kg and 12.2 kg for the two hybrid solutions.

The estimated weight of the aluminum parts was determined with the help of the gravity casting firm. The calculation was based on a design using magnesium parts, which factored in the additional wall thickness required by the permanent mould casting process for aluminum. The estimated weight of an aluminum seatback was 2.8 kg, while that of the seat frame was about 7.0 kg.

Table 25 shows that the all-magnesium solution, not surprisingly, is more costly but offers the biggest weight reduction, whereas the option involving a magnesium monocoque base and aluminum seatbacks is less costly and generates a cost saving of 29%, but is 66% heavier than the all-magnesium solution.

Table 25. Cost Comparison Between an All-Magnesium Solution Using Permanent Mould Casting and Hybrid Solutions Using Aluminum

	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8
	Unit Costs ($) per Annual Volume Produced							
Total for Double Seats	250	500	1,000	1,500	2,500	3,750	5,000	7,500
All-magnesium solution (5.9 kg)	248	238	233	227	222	222	222	222
Magnesium base and aluminum seatback (8.7 kg)	192	172	167	161	161	157	157	157
Aluminum base and magnesium seatbacks (9.8 kg)	253	211	208	208	201	201	201	201

annual volumes of 100 motor coaches ($250 per motor coach). For operators, a motor coach equipped with magnesium seats produces a direct saving of some $6,000 during the vehicle's service life. For major operators with fleets of several hundred motor coaches, this translates into several million dollars of additional profit.

In terms of reduced CO_2 emissions, the impact of a weight reduction of 375 kg per motor coach is relatively small – about 1.14 tonnes per year, or some 17 tonnes per motor coach during its estimated service life of 15 years. However, this lighter-weight solution can be employed in complementarity with other technical solutions for achieving lighter weight and thus reduce CO_2 emissions.

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The estimated weight of the aluminum parts was determined with the help of the gravity casting firm. The calculation was based on a design using magnesium parts, which factored in the additional wall thickness required by the permanent mould casting process for aluminum. The estimated weight of an aluminum seatback was 2.8 kg, while that of the seat frame was about 7.0 kg.

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	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8
	Unit Costs ($) per Annual Volume Produced							
Total for Double Seats	**250**	**500**	**1,000**	**1,500**	**2,500**	**3,750**	**5,000**	**7,500**
All-magnesium solution (5.9 kg)	248	238	233	227	222	222	222	222
Magnesium base and aluminum seatback (8.7 kg)	192	172	167	161	161	157	157	157
Aluminum base and magnesium seatbacks (9.8 kg)	253	211	208	208	201	201	201	201

When the costs are compared with those of the steel solution used as a reference, it is worth noting that the two hybrid solutions offer a cost saving as well as lower weight. More specifically, the solution involving an aluminum monocoque base generates a saving of between 1% and 5%, compared with the steel solution, depending on volumes and the amortization period of the equipment. For the solution involving aluminum seatbacks, the saving varies between 17% and 24%.

In terms of life cycle costs, the savings resulting from a lighter-weight solution are about $12,000 during the service life of a motor coach if an all-magnesium solution is used and about $10,000 or $9,000 if one or other hybrid solution is used. The reduction in CO_2 emissions would be 17 tonnes during the service life of a motor coach if an all-magnesium solution is used and 13 or 14 tonnes if one or other hybrid solution is used.

To conclude, the hybrid option combining magnesium and aluminum is definitely a better option than the conventional steel solution because it offers both a significant cost reduction and a weight reduction. The more interesting choice is the one where magnesium is used for the base (the largest part) and aluminum is used for the seatbacks, which results in optimal and cost. However, it should be remembered that an all-magnesium solution based on a scenario combining pressure die casting and Thixomolding processes offers an even greater saving as well as a bigger weight reduction than the hybrid option using a permanent mould casting process, if sufficient quantities are produced.

5. CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY OF FACTS

This study looked at the main questions concerning the development of magnesium seats that are usually raised by industry representatives. The seat design targeted in the study could result in a weight reduction of more than 375 kg per motor coach.

Flammability risks: It was demonstrated in Chapter 3 that magnesium passes by a wide margin the principal safety tests required by the motor coach industry and the North American railway industry.

Mechanical properties: Many uses of magnesium for structural applications in the automobile industry, including seat applications, were outlined in Chapters 2 and 3. It was also demonstrated in Chapter 3 that automobile industry standards are more rigorous than the strictest motor coach industry standards. It can therefore be concluded that designing a passenger seat to meet industry standards does not pose a major problem.

It should also be pointed out that there is a potential to increase passenger comfort because of the properties of magnesium, which more effectively absorbs energy and vibrations than steel or aluminum.

Economic viability: The case study in Chapter 4 provided an analysis of the costs and limitations of various magnesium casting processes used to manufacture seat components.

- It was demonstrated that the permanent mould casting process offered the lowest cost and required the least amount of investment to commercially produce seats up to a cumulative volume of 5,000 to 5,250 double seats.
- As soon as total volumes exceed 5,250 units, the option combining the conventional pressure die casting process for the monocoque cushion frame and the Thixomolding process for the seatback frames offered the lowest cost.
- The option using vertical injection pressure die casting could be a more economical alternative to conventional pressure die casting. Presses with sufficient capacity should be on the market soon.

The following were the findings when the breakdown of equipment costs, production costs and savings in assembly costs were analysed.

- When production volumes reach 2,500 double seats (100 motor coaches), the magnesium solution using a permanent mould casting process represents an additional cost of 4% and a weight reduction of around 20% to 35%, compared with the cost of manufacturing a typical steel seat.
- For annual production volumes of around 2,500 double seats (100 motor coaches), the additional cost per kilogram of lower weight was less than the limit of $1.75 usually deemed acceptable by some motor coach manufacturers.

- With the magnesium solution, motor coach operators can realize a direct saving of some $400 per year per motor coach in terms of gasoline expenses and wear and tear on brakes and tires. These savings also help recover the additional costs arising from production volumes of 20 motor coaches in about two years and in less than one year for annual production volumes of 100 motor coaches.
- A hybrid solution combining magnesium and aluminum is already a more profitable alternative to steel seats because it offers both a cost saving and a weight reduction.
- For annual production volumes corresponding to 150 motor coaches (3,750 double seats), a magnesium solution combining pressure die casting and Thixomolding processes would generate a cost saving of nearly 40%, compared with the current steel solution.

5.2 CONCLUSION

In light of the above facts, it appears that a lighter-weight solution would be technically possible and economically viable.

In technical terms, the study helped explain the following.

- Magnesium meets all of the flammability standards required by the automobile, bus and railway industries.
- If combined with an excellent seat design consistent with the casting process selected for production, magnesium's ability to absorb energy during a collision could, in some cases, increase the safety of passengers projected forward onto the seatbacks in front of them.
- Magnesium's ability to absorb vibration should help reduce vibrations transmitted to passengers and provide greater comfort on long trips.

The final decision on the choice of materials (magnesium and/or aluminum) may vary depending on the objectives of seat manufacturers, motor coach manufacturers and final buyers. However, the following should be considered when choosing these materials:

- The development of a magnesium seat produces a weight reduction of about 375 kg per motor coach, compared with a reduction of less than 200 kg with an aluminum design.
- The greater the weight reduction, the easier it is for operators to increase the payloads of their motor coaches, comply with the weight standards for various types of axles, and reduce fuel consumption and wear and tear on parts, such as brakes and tires.
- The use of magnesium would make it possible to manufacture ergonomic seats with thinner wall parts than would be possible with aluminum.
- Magnesium's ability to absorb vibration is a substantial benefit, compared with aluminum.
- The greater the weight reduction, the greater the reduction will be in greenhouse gas emissions and wear and tear on road infrastructure.

If the objectives are strictly economic, then an all-aluminum solution or a hybrid solution combining aluminum and magnesium are the best choices. However, these choices also include some disadvantages that should be pointed out.

- With the permanent mould casting process using aluminum alloys, thicker walls are required for parts. Because the density of aluminum is 33% higher than that of magnesium to begin with, an aluminum part will usually be twice as heavy as a magnesium part because it has thicker walls. For example, the estimated weight of an aluminum cushion frame is more than 7.0 kg, while the weight of the magnesium version is 3.1 kg.
- According to the comments received from motor coach fleet operators, operators are looking for seats that are comfortable on long trips as well as noise-free, regardless of wear and tear on seat components. Given these requirements, magnesium's energy and vibration absorption properties can be a key factor. It would be worthwhile to conduct additional tests to measure the actual impact of these properties.
- Operators would like to reduce the bulkiness of seats as much as possible in order to provide more space for seated passengers. To achieve this objective, magnesium's greater fluidity can be a significant benefit because it allows more complex shapes to be moulded than aluminum. Because this fluidity makes it possible to cast thinner walls, the weight of each seat component can be reduced.

However, if the objectives are greater weight reduction while keeping costs competitive, the hybrid option of a magnesium base and aluminum seatbacks using a permanent mould casting process is the one that should be considered to start with. Once volumes reach a certain level, a gradual move toward an all-magnesium solution using pressure die casting and Thixomolding processes could be considered, which would further reduce both weight and cost.

It would only take a single motor coach manufacturer to commit to switching over to a hybrid magnesium-aluminum solution in order to quickly generate cost savings compared to the conventional steel solution. However, it is important to note that it would be in the interest of the industry as a whole to switch over to an all-magnesium solution (using pressure die casting and Thixomolding processes) and thus recover all benefits of the material's advantages (cost, weight and comfort).

5.3 RECOMMENDATIONS

Commercial aspects

Based on the principal facts outlined in this study, the following are recommendations with regard to the marketing potential of lighter-weight seats.

- The development of a lighter-weight seat, made either of aluminum or an aluminum-magnesium hybrid, is now economically profitable and should be the starting point for marketing a new line of products to replace steel seats.
- To promote rapid attainment of the volumes required to generate a maximum of interest in an all-magnesium solution, marketing efforts should target not only the

Canadian/American market, but also the Mexican market within the context of NAFTA. This market could be developed through strategic alliances.

Because the current players in the Mexican market are often active in the Brazilian market and because several manufacturers in these two countries are European, a lighter-weight seat can quickly be marketed worldwide. Groups such as Volvo Bus (Prévost Car in Canada and Volvo Bus in Mexico), DaimlerChrysler (Setra in the United States and Europe, Mercedes in Mexico) and Irizar (Mexico, South America and Europe) can be targeted in order to promote rapid adoption and growth.

- Given the international potential of magnesium seats and the mechanical properties of magnesium alloys, it would be worthwhile to consider adapting the seat to meet European standards by including three-point seatbelts.
- Given the interest of certain high-speed train manufacturers, it would be possible to consider a seat design that could also meet the needs of this industry, which would increase production volumes and significantly reduce manufacturing costs.

Technical aspects

This study was conducted to investigate the technical and economic feasibility of magnesium seats. In order to proceed with the development and marketing of magnesium seats, some technical aspects should now be examined in depth. The following are recommendations in that regard:

- Finalize the seat design proposed in the case study (and possibly adopt it for a hybrid solution) and carry out the required structural analyses to meet the European ECE 80 standard and to validate the weight reduction possible with magnesium and/or aluminum seats complying with this standard.
- In view of the market opportunities, incorporate the attachment points for a three-point seatbelt into the new design.
- In close co-operation with experts in the selected casting technologies, continue developing the high-tech design in order to optimize the seat design, make maximum use of the properties of the selected alloys and accurately determine potential weight savings.
- Optimize the design in order to minimize the bulkiness of various seat components and improve seat ergonomics to provide passengers with greater comfort over long distances.
- To further optimize the proposed design, conduct a comparative and quantitative analysis of both the AM60B magnesium alloy typically used by the automobile industry and new alloys with enhanced properties, particularly those of Noranda and Dead Sea Magnesium.
- Conduct collision and corrosion tests on all exposed structural parts and conduct any other mechanical test for validating the final design.
- Carry out an actual case study with assembled magnesium or hybrid seat prototypes installed in an operating motor coach.

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APPENDIX A – PERSONS CONTACTED

List of resource persons contacted during the study.

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APPENDIX B – BODYCOTE REPORTS

The following are the Bodycote analysis reports for magnesium samples:

- Report No 04-02-168(A)
  ASTM E 162 Surface Flammability of "Extruded Alloy AZ31"
- Report No 04-02-168(B1)
  ASTM E 662 Rate of Smoke Generation of "Magnesium Alloy AM60B"
- Report No 04-02-168(B2)
  Bombardier SMP 800-C Toxic Gas Generation of "Magnesium Alloy AM60B"
- Report No 04-02-168(B3)
  Caloric Content of "Magnesium Alloy AM60B"

Bodycote MATERIALS TESTING CANADA INC

BODYCOTE • 2395 SPEAKMAN DRIVE, MISSISSAUGA, ONTARIO, CANADA L5K 1B3 • TEL: (905) 822-4111 • FAX: (905) 823-1446

ASTM E 162 Surface Flammability of "Extruded Alloy AZ31"

A Report To: **IC² Technologies Inc.**
4800 Rideau, Suite A
Québec City, Québec
G1P 4P4

Phone: (418) 659-5005
Fax: (418) 658-5336

Attention: François Bergeron

Submitted By: Fire, Flammability & Explosivity

Report No. 04-02-168(A)
2 pages + 1 appendix

Date: March 30, 2004

ACCREDITATION

Standards Council of Canada, Registration #1.

REGISTRATION

ISO 9002-1994, registered by QMI, Registration #001109.

SPECIFICATIONS OF ORDER

Determine surface flammability in accordance with ASTM E 162, as per your P.O. #04-1001 and our Quotation No. 04-02-0000167 accepted March 23, 2004.

IDENTIFICATION

(BMTC sample identification number 04-02-S0168-1)

Solid, extruded, magnesium alloy material, approximately 2.3 mm in thickness, identified as "AZ31".

TEST RESULTS

ASTM E 162-02a

Surface Flammability of Materials Using a Radiant Heat Energy Source. (Is = Flame Spread Index).

	Fs	Q	Is	Observations
1:	1.0	2.4	2	Specimens did not ignite.
2:	1.0	1.4	1	No flaming running or flaming dripping observed.
3:	1.0	1.4	1	
4:	1.0	2.0	2	
Rounded Average:			<5	
Specified Maximum:			35	No flaming running or flaming dripping

CONCLUSIONS

The magnesium alloy material identified in this report, when tested at an approximate thickness of 2.3 mm, meets The Federal Railroad Administration requirements as they pertain to surface flammability (ASTM E 162).

Note: This is an electronic copy of the report. Signatures are on file with the original report.

M. Laniel,
Fire, Flammability & Explosivity

Richard J. Lederle,
Fire, Flammability & Explosivity

Note: This report consists of 2 pages, including the cover page, that comprise the report "body". It should be considered incomplete if all pages are not present. Additionally, the Appendix of this report comprises a cover page, plus 1 page.

APPENDIX

(1 Page)

Summary of Test Procedure

ASTM E 162-02a

Surface Flammability of Materials Using a Radiant Energy Source.

Four specimens, 6 x 18 inches in size, are pre-dried for 24 hours at 60°C and conditioned to equilibrium at 50 ± 5% relative humidity and 23 ± 3°C before testing.

Each specimen is mounted into a holder and inclined at 30° from the vertical in front of a 12 x 18 inch gas-fired radiant panel. The orientation of the specimen is such that ignition is forced near its upper edge by a pilot flame, and the flame front progresses downwards.

A factor derived from the rate of progress of the flame-front and the rate of heat liberation by the material under test is calculated as follows and then reported after rounding the average of the tests to the nearest multiple of 5:

$$I_s = F_s \cdot Q$$

Where: Is is the flame spread index

Fs is the flame spread factor

Q is the heat evolution factor

Transit authorities generally specify a maximum Is acceptance criterion of 35 for general applications, and 100 for light diffusers, windows and transparent plastic windscreens.

Bodycote MATERIALS TESTING CANADA INC.

BODYCOTE • 2395 SPEAKMAN DRIVE, MISSISSAUGA, ONTARIO, CANADA L5K 1B3 • TEL: (905) 822-4111 • FAX: (905) 823-1446

ASTM E 662 Rate of Smoke Generation of "Magnesium Alloy AM60B"

A Report To: **IC² Technologies Inc.**
4800 Rideau, Suite A
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Phone: (418) 659-5005
Fax: (418) 658-5336

Attention: François Bergeron

Submitted By: Fire, Flammability & Explosivity

Report No. 04-02-168(B1)
3 pages + 1 appendix

Date: March 30, 2004

ACCREDITATION Standards Council of Canada, Registration #1.

REGISTRATION ISO 9002-1994, registered by QMI, Registration #001109.

SPECIFICATIONS OF ORDER

Determine rate of smoke generation according to ASTM E 662, as per your P.O. #04-1001 and our Quotation No. 04-02-0000167 accepted March 23, 2004.

IDENTIFICATION

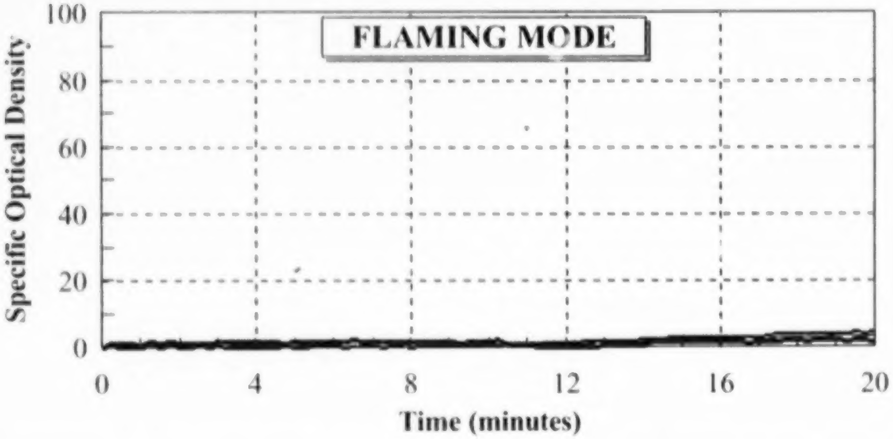
Solid, magnesium alloy material, approximately 4.3 mm in thickness, identified as "AM60B".

(BMTC sample identification number 04-02-S0168-2)

TEST RESULTS

ASTM E 662-03

Specific Optical Density of Smoke Generated by Solid Materials

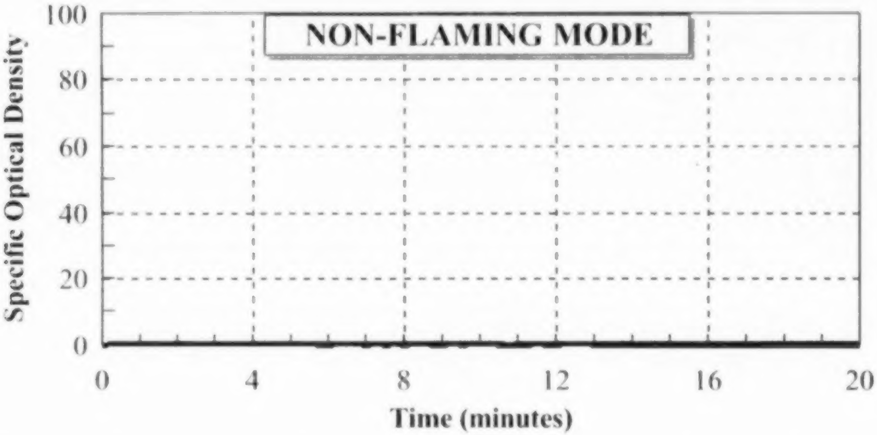


Flaming Mode	Test	#1	#2	#3	Average	Specified Maxima
Specific Optical Density at 1.5 minutes		2	1	1	1	100
Specific Optical Density at 4.0 minutes		2	1	1	1	200
Maximum Specific Optical Density		2	5	4	4	-
Maximum Corrected Optical Density		2	5	4	4	-

TEST RESULTS (Cont..)

ASTM E 662-03

Specific Optical Density of Smoke Generated by Solid Materials



Non-Flaming Mode	Test	#1	#2	#3	Average	Specified Maxima
Specific Optical Density at 1.5 minutes		0	1	0	0	100
Specific Optical Density at 4.0 minutes		0	1	1	1	200
Maximum Specific Optical Density		0	1	1	1	-
Maximum Corrected Optical Density		0	1	1	1	-

CONCLUSIONS

The solid magnesium alloy material identified in this report, when tested at an approximate thickness of 4.3 mm, meets the Federal Railroad Administration requirements as they pertain to rate of smoke generation (ASTM E 662).

Note: This is an electronic copy of the report. Signatures are on file with the original report.

I. Smith,
Fire, Flammability & Explosivity

Richard J. Lederle,
Fire, Flammability & Explosivity

Note: This report consists of 3 pages, including the cover page, that comprise the report "body". It should be considered incomplete if all pages are not present. Additionally, the Appendix of this report comprises a cover page, plus 1 page.

APPENDIX

(1 Page)

Summary of Test Procedure

ASTM E 662-03

Specific Optical Density of Smoke Generated by Solid Materials (NBS Smoke Chamber)

This method of test covers a procedure for measuring the smoke generated by solid materials and assemblies in thickness up to and including 1 inch (25.4 mm). Measurement is made of the attenuation of a light beam by smoke (suspended solid or liquid particles) accumulating within a closed chamber due to nonflaming pyrolytic decomposition and flaming combustion. Results are expressed in terms of specific optical density (Ds), which is derived from a geometrical factor and the measured optical density (absorbance).

Specimens are dried for 24 hours at 60°C and conditioned to equilibrium at 50% RH and 23°C.

Three specimens, 3" square, are exposed to each mode of combustion. The % light transmittance during the course of the combustion is recorded. These data are used to express the quantity of smoke in the form of Specific Optical Density based on the following formula which assumes the applicability of Bouguer's law:

$$Ds = (V/AL)\cdot\log(100/T) = G\cdot\log(100/T) = 132\cdot\log(100/T)$$

Where: Ds = Specific Optical Density
T = % Transmittance
V = Chamber Volume ($18\ ft^3$)
A = Exposed Area of the Sample ($0.0456\ ft^2$)
L = Length of Light Path in Chamber (3.0 ft)
G = Geometric Factor

Among the parameters normally reported are:

$Ds_{1.5}$	- specific optical density after 1.5 minutes
$Ds_{4.0}$	- specific optical density after 4.0 minutes
Dm	- maximum specific optical density at any time during the 20 minute test
$Dm_{(corr)}$	- Dm corrected for incidental deposits on the optical surfaces

Transit authorities generally specify a maximum Ds 1.5 of 100 and a maximum Ds 4.0 of 200 in either flaming or non-flaming test mode.

Bodycote MATERIALS TESTING CANADA INC.

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Bombardier SMP 800-C Toxic Gas Generation of "Magnesium Alloy AM60B"

A Report To: **IC² Technologies Inc.**
4800 Rideau, Suite A
Québec City, Québec
G1P 4P4

Phone: (418) 659-5005
Fax: (418) 658-5336

Attention: François Bergeron

Submitted By: Fire, Flammability & Explosivity

Report No. 04-02-168(B2)
3 pages + 1 appendix

Date: March 30, 2004

ACCREDITATION Standards Council of Canada, Registration #1.

REGISTRATION ISO 9002-1994, registered by QMI, Registration #001109.

SPECIFICATIONS OF ORDER

Determine toxic gas production according to Bombardier SMP 800-C, as per your P.O. #04-1001 and our Quotation No. 04-02-0000167 accepted March 23, 2004.

IDENTIFICATION

Solid, magnesium alloy material, approximately 4.3 mm in thickness, identified as "AM60B".

(BMTC sample identification number 04-02-S0168-2)

TEST RESULTS

Bombardier SMP 800-C

Toxic Gas Generation

		Flaming Mode	Non-Flaming Mode	Specified Maxima
Carbon Monoxide (CO ppm)	at 1.5 minutes	<10	<10	-
	at 4.0 minutes	<10	<10	-
	at maximum	75	<10	3500
Carbon Dioxide (CO2 ppm)	at 1.5 minutes	200	<50	-
	at 4.0 minutes	1200	<50	-
	at maximum	9250	<50	90000

TEST RESULTS (Cont..)

Bombardier SMP 800-C

Toxic Gas Generation

	Flaming Mode	Non-Flaming Mode	Specified Maxima
Nitrogen Oxides (as NO2 ppm)	2	2	100
Sulphur Dioxide (SO2 ppm)	<1	<1	100
Hydrogen Chloride (HCl ppm)	<2	<2	500
Hydrogen Fluoride (HF ppm)	<2	<2	100
Hydrogen Bromide (HBr ppm)	<1	<1	100
Hydrogen Cyanide (HCN ppm)	<1	<1	100
Original Weight (g)	41.5	41.7	-
Final Weight (g)	41.4	41.7	-
Weight Loss (g)	0.0	0.0	
Weight Loss (%)	0.02	0.00	-
Time to Ignition (s)	Did not ignite		-
Burning Duration (s)	-	-	-

CONCLUSIONS

The solid magnesium alloy material identified in this report, when tested at an approximate thickness of 4.3 mm, meets Bombardier requirements as they pertain to toxic gas production (Bombardier SMP 800-C).

Note: This is an electronic copy of the report. Signatures are on file with the original report.

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Fire, Flammability & Explosivity

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APPENDIX

(1 Page)

Summary of Test Procedure

Bombardier SMP 800-C

Toxic Gas Sampling and Analytical Procedures

Toxic Gas Generation

Gases produced for analysis are generated in a specified, calibrated smoke chamber during standard rate of smoke generation testing (typically ASTM E 662), in both flaming combustion and non-flaming pyrolytic decomposition test modes.

Carbon Monoxide (CO) and Carbon Dioxide (CO2)

CO and CO2 are monitored continuously during the 20 minute test using a non-dispersive infrared (NDIR) analyzer. Data are reported in ppm by volume at 1.5 and 4.0 minutes and at maximum concentration.

Acid Gas Sampling

HCN, HF, HCl, HBr, NOx and SO2 are sampled by drawing 6 litres of the chamber atmosphere through two midget impingers, each containing 10 ml of 0.25N NaOH, at a rate of 400 ml per minute. The 15 minute sampling period is commenced at the 4 minute mark. All determinations are performed in both the flaming and non-flaming modes and all data are reported in parts per million (ppm) by volume in air.

Analysis of Impingers for Hydrogen Cyanide (HCN)

Cyanide in the NaOH impinger, as NaCN, is converted to CNCl by reaction with chloramine-T at pH greater than 8 without hydrolyzing to CNO^-. After the reaction is complete, CNCl forms a red-blue colour on addition of a pyridine-barbituric acid reagent. Cyanide is quantified by spectrometric measurement of the increase in colour 578 nm. Reference: In-house SOP 00-13-SP-1216 based on ASTM Method D 2036-91

Analysis of Impingers for Hydrogen Fluoride (HF)

Fluoride, as NaF, in the NaOH impinger is determined using SPADNS colorimetry.
Reference: In-house SOP 01-13-SP-1295

Analysis of Impingers for Hydrogen Chloride (HCl) and Hydrogen Bromide (HBr)

Alkali halides (chloride and bromide) formed in the NaOH solution are measured using ion chromatography and conductivity detection. Reference: In-house SOP 93-T34-SP-007

Analysis of Impingers for Nitrogen Oxides (NOX)

Nitrite and nitrate formed in the alkaline solution are determined using ion chromatography and conductivity detection. The nitrite and nitrite results are combined and the total expressed as nitrogen dioxide (NO2).
Reference: In-house SOP 93-T34-SP-007

Analysis of Impingers for Sulphur Dioxide (SO2)

SO2 is trapped in the NaOH impinger as sulphite and sulphate ($SO3^{-2}$ and $SO4^{-2}$). Hydrogen peroxide is added to convert $SO3^{-2}$ to $SO4^{-2}$. Resulting sulphate is determined using ion chromatography and conductivity detection. Reference: In-house SOP 93-T34-SP-007

Bodycote MATERIALS TESTING CANADA INC.

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Caloric Content of "Magnesium Alloy AM60B"

A Report To: **IC² Technologies Inc.**
4800 Rideau, Suite A
Québec City, Québec
G1P 4P4

Phone: (418) 659-5005
Fax: (418) 658-5336

Attention: François Bergeron

Submitted By: Fire, Flammability & Explosivity

Report No. 04-02-168(B3)
8 pages + 1 appendix

Date: March 30, 2004

ACCREDITATION Standards Council of Canada, Registration #1.

REGISTRATION ISO 9002-1994, registered by QMI, Registration #001109.

SPECIFICATIONS OF ORDER

Determine Effective Heat of Combustion according to ASTM E 1354 and derive Caloric Content, as per your P.O. #04-1001 and our Quotation No. 04-02-000167 accepted March 23, 2004.

IDENTIFICATION

Solid, magnesium alloy material, approximately 4.1 mm in thickness, identified as "AM60B".

(BMTC sample identification number 04-02-S0168-2)

SUMMARY OF TEST PROCEDURE

Three specimens, 100 mm x 100 mm in size, are conditioned to equilibrium at 50 ± 5% relative humidity and 23 ± 3°C before testing.

Each specimen is mounted into a holder and placed horizontally below a cone-shaped radiant heat source which has been previously set to emit a specified heat flux. A spark source is located 13 mm above the surface of the specimen in order to promote ignition in ambient air conditions, while a load cell continuously monitors specimen weight loss.

Exhaust gas flow rate and oxygen concentration are used to determine the amount of heat release, based on the observation that the net heat of combustion is directly related to the amount of oxygen required for combustion. The relationship is that approximately 13100 kJ of heat are released per 1 kg of oxygen consumed.

In addition to rate of heat release, other measurements include mass-loss rate, time to sustained flaming and smoke obscuration.

TEST RESULTS ASTM E 1354-03

Heat and Visible Smoke Release Rates for Materials and Products
Using an Oxygen Consumption Calorimeter

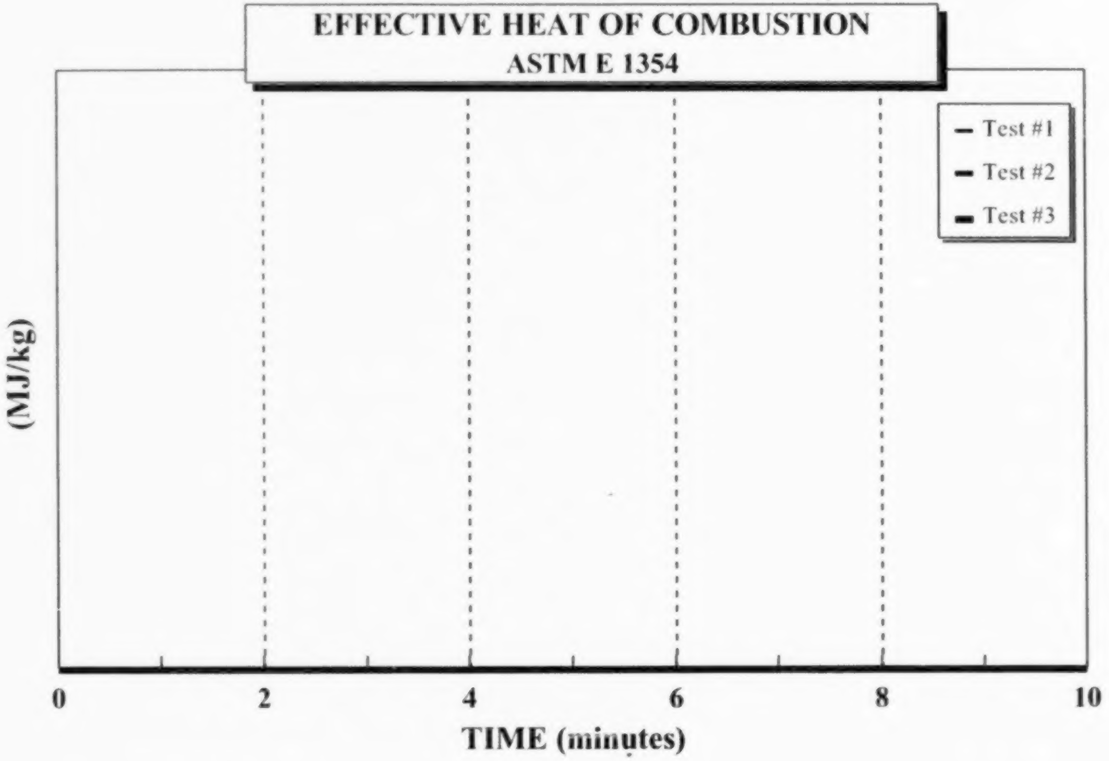
Heat Flux: 50 kW/m^2 Exhaust Flow Rate: 24.0 l/s

Testing was performed in the horizontal configuration and using the specimen holder edge frame.

	Test #1	Test #2	Test #3	Average	
Specimen Thickness (mm)	4.1	4.1	4.1		
Initial Mass (g)	74.5	74.1	73.4		
Final Mass (g)	74.0	74.0	73.4		
Total Mass Loss (kg/m^2)	0.05	0.00	0.00	0.02	
Peak Mass Loss Rate (g/s·m^2)	0.56	0.27	0.00	0.28	
Average Mass Loss Rate (g/s·m^2)	0.12	0.12	0.12	0.12	
Time to Ignition (s)	-	-	-	-	
Time to Flame-out (s)	-	-	-	-	
Time of Peak Rate of Heat Release (s)	580	115	560	418	
Peak Rate of Heat Release (kW/m^2)	5.7	0.6	8.7	5.0	
Average Rate of Heat Release (kW/m^2)	0.7	0.0	0.4	0.4	
Total Heat Released (MJ/m^2)	0.40	0.00	0.25	0.22	
Average Effective Heat of Combustion (MJ/kg)	-	-	-	-	*
Average Effective Heat of Combustion (BTU/lb)	-	-	-	-	*
Caloric Content (MJ/kg)	-	-	-	-	**
Caloric Content (BTU/lb)	-	-	-	-	**
Peak Extinction Area (m^2/kg)	-	-	-	-	
Average Extinction Area (m^2/kg)	-	-	-	-	

* Total heat produced per unit mass of material consumed
** Total heat produced per unit mass of material tested

TEST RESULTS (Cont..)

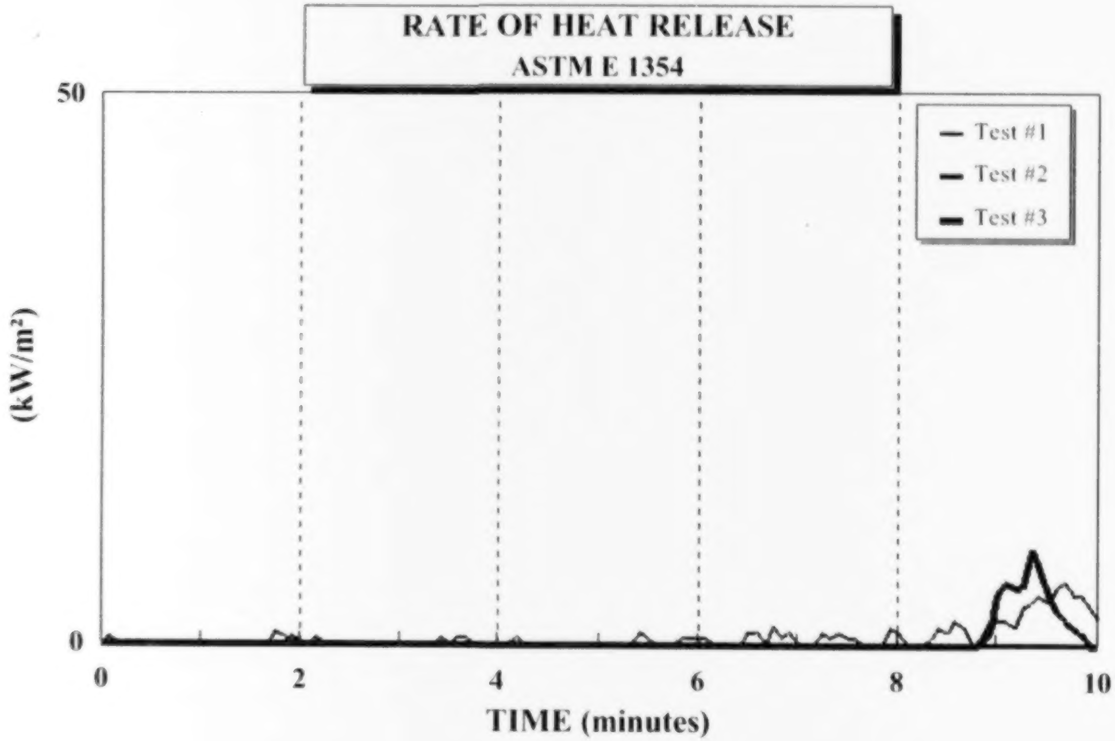


	Test #1	Test #2	Test #3	Average
Average Heat of Combustion (MJ/kg)*	-	-	-	-
Heat of Combustion @ 60 s (MJ/kg)**	-	-	-	-
Heat of Combustion @ 180 s (MJ/kg)**	-	-	-	-
Heat of Combustion @ 300 s (MJ/kg)**	-	-	-	-

* Averaged over the period starting when 10% of the ultimate mass loss occurred and ending at the time when 90% of the ultimate mass loss occurred.

** Averages over the 60, 180 or 300 second periods starting when 10% of the ultimate mass loss occurred.

TEST RESULTS (Cont..)

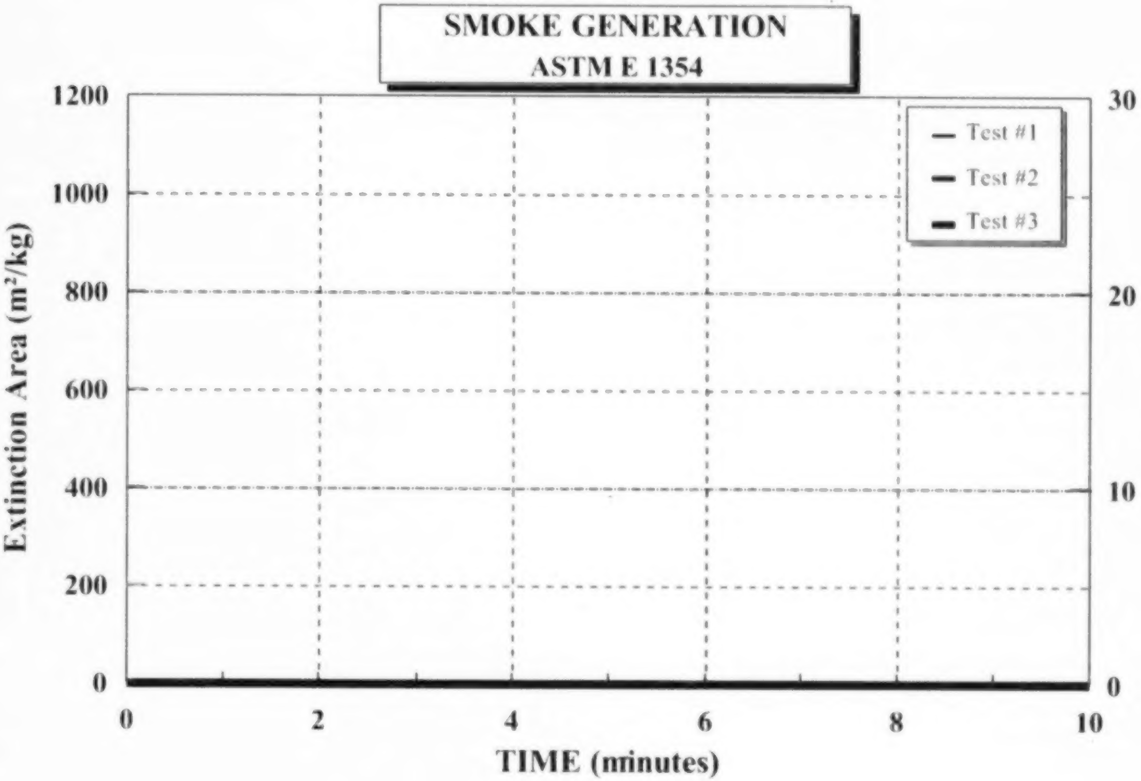


	Test #1	Test #2	Test #3	Average
Peak Rate of Heat Release (kW/m²)	5.7	0.6	8.7	5.0
Average Heat Release Rate (kW/m²)*	0.7	0.0	0.4	0.4
Heat Release Rate @ 60 s (kW/m²)**	0.0	0.0	0.0	0.0
Heat Release Rate @ 180 s (kW/m²)**	0.1	0.0	0.0	0.0
Heat Release Rate @ 300 s (kW/m²)**	0.1	0.0	0.0	0.0

* Averaged over the test period (from ignition to flameout).

** Averages over the first 60, 180 or 300 seconds after ignition.

TEST RESULTS (Cont..)

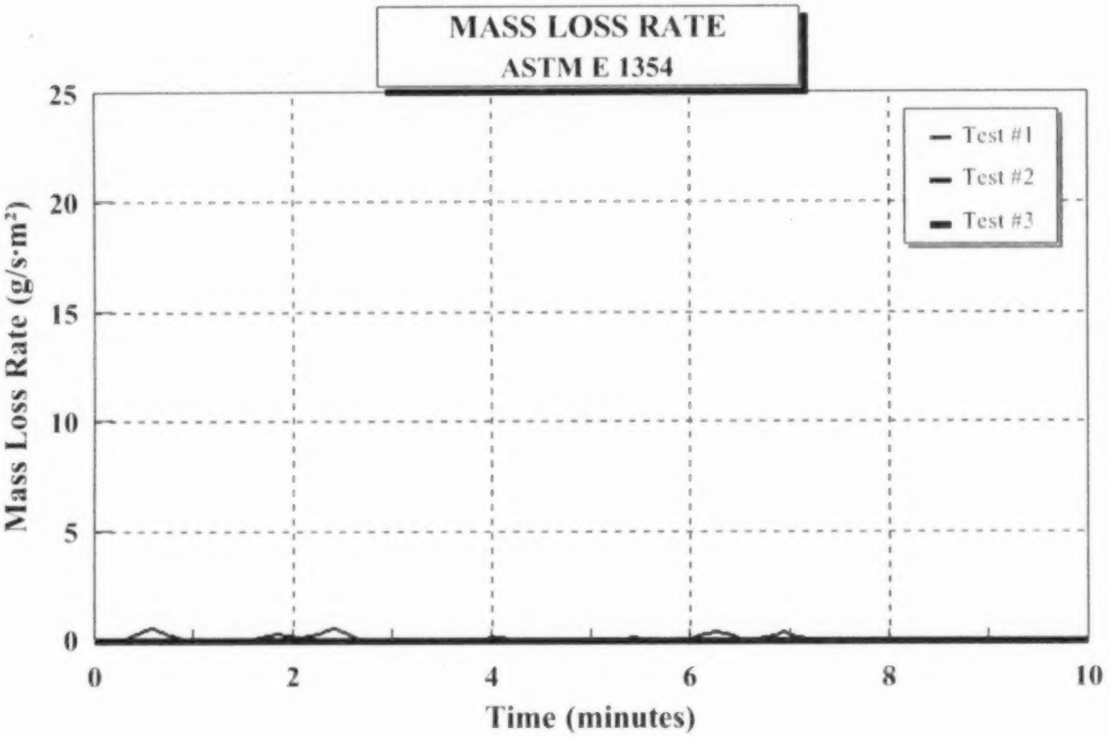


	Test #1	Test #2	Test #3	Average
Peak Extinction Area (m²/kg)	-	-	-	-
Average Extinction Area (m²/kg)*	-	-	-	-
Extinction Area @ 60 s (m²/kg)**	-	-	-	-
Extinction Area @ 180 s (m²/kg)**	-	-	-	-
Extinction Area @ 300 s (m²/kg)**	-	-	-	-
Total Smoke (m²)	-	-	-	-

* Averaged over the test period (from ignition to flameout).

** Averages over the first 60, 180 or 300 seconds after ignition.

TEST RESULTS (Cont..)



	Test #1	Test #2	Test #3	Average
Peak Mass Loss Rate (g/s·m²)	0.56	0.27	0.00	0.28
Average Mass Loss Rate (g/s·m²)*	0.12	0.12	0.12	0.12
Mass Loss Rate @ 60 s (g/s·m²)**	0.19	0.19	0.19	0.19
Mass Loss Rate @ 180 s (g/s·m²)**	0.17	0.17	0.17	0.17
Mass Loss Rate @ 300 s (g/s·m²)**	0.12	0.12	0.12	0.12

* Averaged over the period starting when 10% of the ultimate mass loss occurred and ending at the time when 90% of the ultimate mass loss occurred.

** Averages over the 60, 180 or 300 second periods starting when 10% of the ultimate mass loss occurred.

CONCLUSIONS

The magnesium alloy identified in this report, when tested at an approximate thickness of 4.1 mm, did not ignite or show signs of heat evolution. Data collection was continued for a time period of 10 minutes according to ASTM E 1354 at an imposed heat flux of 50 kW/m².

Note: This is an electronic copy of the report. Signatures are on file with the original report.

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APPENDIX

(1 Page)

ASTM E 1354 Definitions

ASTM E 1354 DEFINITIONS

In evaluating the data produced by the oxygen consumption (cone) calorimeter, the following definitions and comments are offered:

Effective Heat of Combustion	This is the measured heat release divided by the mass loss for a specified time period and represents, therefore, the calorific value of the consumed portion only of the tested material. Caloric content under the test conditions can be derived by dividing the total heat released by the original mass of the material under test. It generally differs from the theoretical heat of combustion, since the latter involves complete combustion - a phenomenon which rarely takes place in an actual fire.
Time to Ignition	Also known as ignition delay time, this parameter provides a measure of a material's propensity to ignition as measured by the time to sustained ignition at a given heat flux. It can also be considered to be related to the volatility of the degradation products and the time required to achieve a critical fuel concentration in the vapour phase. This gasification rate is temperature dependent: the higher the imposed heat flux the shorter the time to ignition.
Heat Release Rate (HRR)	HRR is the heat evolved per unit time and is highly dependent on applied heat flux: the higher the flux the greater the HRR. HRR curves can fluctuate significantly with time and it is generally considered that the average HRR can be a better predictor of full-scale fire performance than the peak value.
Total Heat Release	This is the integrated area under the HRR curve over the test period, expressed in MJ/m^3. If one knows the surface area of a material used in a room or transit vehicle, this value is more properly used to estimate "potential heat load" than is the more commonly used "caloric content" based upon the weight of material used.
Mass Loss Rate	This is roughly correlatable with heat release rate because it is the rate at which the test material is degraded to produce combustible fuels. The peak mass loss rate and average mass loss rate are derivative terms generated by the load cell.
Extinction Area	This refers to the "yield" of smoke which is, through mathematical manipulation, expressed as an area per unit mass.

In addition to average values for the test, data averaged to the 60, 180 and 300 second marks after ignition are also typically provided. Where materials burn for different lengths of time, for example, it is more technically sound to compare the average heat release rates over the first 1, 3 or 5 minutes of burning than to compare the test average results which encompass differing time periods.